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(54) Title: MONO DIAMETER WELLBORE CASING

(57) Abstract: An apparatus and system is disclosed for radially expanding and plastically deforming an expandable tubular member. The system may comprise an anchoring mechanism adapted to mate with an end of the expandable tubular member, a tubular member releasibly coupled to the anchoring mechanism, an adjustable expansion mandrel coupled to the tubular member adapted to be controllably expanded to a larger outside dimension for radial expansion of the expandable tubular member or collapsed to a smaller outside dimension an actuator coupled to the adjustable expansion mandrel adapted to controllably longitudinally displace the adjustable expansion mandrel relative to the expandable tubular member; and a gripping device coupled to the locking adapted to controllably engage the expandable tubular member.

MONO DIAMETER WELLBORE CASING**Cross Reference T Related Applications**

[001] The present application claims the benefit of the filing dates of (1) U.S. provisional patent application serial no. 60/380,147, attorney docket no 25791.104, filed on 5/06/2002, the disclosure of which is incorporated herein by reference.

[002] The present application is related to the following: (1) U.S. patent application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, (4) U.S. patent application serial no. 09/440,338, attorney docket no. 25791.9.02, filed on 11/15/1999, (5) U.S. patent application serial no. 09/523,460, attorney docket no. 25791.11.02, filed on 3/10/2000, (6) U.S. patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, (7) U.S. patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, (8) U.S. patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, (9) U.S. patent application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, (10) PCT patent application serial no. PCT/US00/18635, attorney docket no. 25791.25.02, filed on 7/9/2000, (11) U.S. provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (12) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (13) U.S. provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (14) U.S. provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (15) U.S. provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (16) U.S. provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (17) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (18) U.S. provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (19) U.S. provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (20) U.S. provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (21) U.S. provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (22) U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001, (23) U.S. provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (24) U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (25) U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (26) U.S. provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (27) U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, (28) U.S. provisional patent application serial no. 60/3318,386, attorney docket no.

25791.67.02, filed on 9/10/2001, (29) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (30) U.S. utility patent application serial no. 10/016,467, attorney docket no. 25791.70, filed on 12/10/2001; (31) U.S. provisional patent application serial no. 60/343,674, attorney docket no. 25791.68, filed on 12/27/2001; (32) U.S. provisional patent application serial no. 60/346,309, attorney docket no. 25791.92, filed on 1/7/2002; (33) U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/2002; and (34) U.S. provisional patent application serial no. 60/372,632, attorney docket no. 25791.101, filed on 4/15/2002, the disclosures of which are incorporated herein by reference.

Background of the Invention

[003] This invention relates generally to oil and gas exploration, and in particular to forming and repairing wellbore casings to facilitate oil and gas exploration and production.

[004] Conventionally, when a wellbore is created, a number of casings are installed in the borehole to prevent collapse of the borehole wall and to prevent undesired outflow of drilling fluid into the formation or inflow of fluid from the formation into the borehole. The borehole is drilled in intervals whereby a casing which is to be installed in a lower borehole interval is lowered through a previously installed casing of an upper borehole interval. As a consequence of this procedure the casing of the lower interval is of smaller diameter than the casing of the upper interval. Thus, the casings are in a nested arrangement with casing diameters decreasing in downward direction. Cement annuli are provided between the outer surfaces of the casings and the borehole wall to seal the casings from the borehole wall. As a consequence of this nested arrangement a relatively large borehole diameter is required at the upper part of the wellbore. Such a large borehole diameter involves increased costs due to heavy casing handling equipment, large drill bits and increased volumes of drilling fluid and drill cuttings. Moreover, increased drilling rig time is involved due to required cement pumping, cement hardening, required equipment changes due to large variations in hole diameters drilled in the course of the well, and the large volume of cuttings drilled and removed.

[005] The present invention is directed to overcoming one or more of the limitations of the existing processes for forming and repairing wellbore casings.

Summary of the Invention

[006] According to one aspect of the present invention, an apparatus and method for forming a mono diameter wellbore casing is provided.

Brief Description of the Drawings

[007] Figs. 1a-1f are conceptual illustrations of one aspect of the present invention.

[008] Figs. 2a-2f are fragmentary cross-sectional illustrations of the placement of an exemplary embodiment of an apparatus for forming a mono diameter wellbore casing within a wellbore that traverses a subterranean formation.

[0009] Figs. 3a-3f are fragmentary cross-sectional illustrations of the apparatus of Figs. 2a-2f after placement on the bottom of the wellbore.

[0010] Figs. 4a-4f are fragmentary cross-sectional illustrations of the apparatus of Figs. 3a-3f after placing a ball or dart within the ball or dart seat to initiate the radial expansion and plastic deformation of the expandable tubular member.

[0011] Figs. 5a-5f are fragmentary cross-sectional illustrations of the apparatus of Figs. 4a-4f after the initiation of the radial expansion and plastic deformation of the aluminum sleeve within the shoe.

[0012] Figs. 6a-6f are fragmentary cross sectional illustrations of the apparatus of Figs. 5a-5f after the completion of the radial expansion and plastic deformation of the aluminum sleeve within the shoe.

[0013] Figs. 7a-7f are fragmentary cross-sectional illustrations of the apparatus of Figs. 6a-6f after displacing the sliding sleeve valve within the shoe to permit circulation around the ball or dart.

[0014] Figs. 8a-8f are fragmentary cross-sectional illustrations of an alternative embodiment of a bottom anchoring apparatus.

[0015] Figs. 9a-9g are fragmentary cross sectional illustrations of certain aspects of the operation of the apparatus of Figs. 8a-8f.

Detailed Description of the Illustrative Embodiments

[0016] Referring initially to Fig. 1a, an embodiment of an apparatus and method for radially expanding a tubular member will now be described. As illustrated in Fig. 1a, a wellbore 100 is positioned in a subterranean formation 105. In an exemplary embodiment, the wellbore 100 may include a casing 110. The wellbore 100 may be positioned in any orientation from vertical to horizontal. Thus, in this application the direction "up", "upper" or "upward" refers to the direction towards the surface termination of the wellbore and the direction "down", "lower" or "downward" refers to the direction towards the bottom or end of the wellbore.

[0017] In order to extend the wellbore 100 into the subterranean formation 105, a drill string (not shown) is used in a well known manner to drill out material from the subterranean formation 105 to form the wellbore 100. The inside diameter of the wellbore 100 is greater than or equal to the outside diameter of the casing 110.

[0018] In an exemplary embodiment, a tubular apparatus 120 having an opening 122 may then be positioned within the wellbore 100 with an upper end 124a of the apparatus 120 initially coupled to a well string 125. The apparatus 120 is adapted to allow fluidic materials to enter the upper end 124a of the tool and exit through the opening 122 positioned at the lower end 124b of the tool, thereby creating a passage (not shown) or fluid flow path 126. The apparatus 120 may include, among other components, a casing lock 130, a gripping device 132, a tension actuator 134, a sealing mechanism 136, an expansion cone 140, a cementing probe 144, and a casing anchor 148.

[0019] The apparatus 120 as illustrated in Fig. 1a is in a "running" or positioning configuration. In other words, the tool is running or traveling down the wellbore. In several exemplary embodiments,

in the running configuration, the lower end 124b of the apparatus 120 extends past the casing 110 into the wellbore. The casing lock 130 may be used to support or couple the apparatus 120 to the casing 110 which may keep the casing 110 positioned above the lower end 124b of the tool when the apparatus 120 is in the running configuration. Alternatively, the expansion cone 140 may be used to support the casing 110 during the running or positioning of the apparatus 120.

[0020] In one embodiment, the gripping device 132 may be positioned close to the upper end 124a of the apparatus 120. In the illustrative embodiment, the gripping device 132 is positioned above the casing lock 130. As will be explained in detail below, the gripping device 132 may be used to keep the casing 110 stationary during the operation of the apparatus 120. A force multiplier or tension actuator 134 may be positioned below the casing lock 130. The tension actuator 134 may be used to "pull" the expansion cone 140 and the lower end 124b of the apparatus 120 inside the casing 110. In the illustrative embodiment, an alternative sealing mechanism 136 may be positioned below the tension actuator 134.

[0021] As illustrated in Fig. 1a, an apparatus for radially expanding a tubular member, such as an expansion cone 140 may then be positioned outside of the casing 110. A tubular member, such as a cementing probe 144, may be positioned below the expansion cone 140. A casing anchor 148, such as a packer or drillable shoe, may be positioned at the lower end 124b of the apparatus 120.

[0022] Turning now to Fig. 1b, there is illustrated the apparatus 120 positioned at the bottom of the wellbore 100. As will be explained in detail below, when the apparatus 120 contacts with the bottom of the wellbore 100, an expansion mechanism 150, coupled to the casing anchor 148, expands radially outward such that the casing 110 cannot move past the expansion mechanism. In one embodiment, the expansion cone 140 may also expand upon impact with the bottom of the well. The expansion cone may expand to a diameter that is greater than the interior diameter of the casing 110.

[0023] In an exemplary embodiment, as illustrated in Fig. 1c, an actuating event may occur to cause the gripping device 132 to grip the casing 110. Such an actuating event may be placing a plug, such as a ball or dart into the apparatus 120 to block the flow path 126 and prevent fluids from exiting through opening 122. Injecting a fluidic material into the apparatus when the flow path 126 is blocked causes an increase in pressure within the tool. The increase pressure may actuate gripping elements of the gripping device 132 thereby locking the top end of the apparatus 120 to the expandable tubular member. In some alternative embodiments, the continued injection of the fluidic material furthermore increases the operating pressure within the tool which causes the expansion cone to expand. The increase operating pressure may also cause the tension actuator 134 to pull the expansion cone 140 into the expandable tubular member. As a result, the casing or expandable casing 110 is radially expanded as the expansion cone 140 travels up the casing 110.

[0024] Turning now to Fig. 1d, the continued upward movement of the expansion cone 140 pulls the casing anchor 148 into the end of the radially expanded casing 110. As a result, the end of the

radially expanded casing 110 will impact the expansion mechanism 150, thereby preventing the casing anchor 148 from moving further in the upward direction. In some embodiments, the continued upward force on the casing anchor 148 may cause the casing anchor to radially expand within the casing to firmly couple the end of the tubular member to the casing anchor 148. In alternative embodiments, this anchoring may also hydraulically seal the anchor 148 to the casing 110.

[0025] The continued upward force on the apparatus 120 may cause the cementing probe 144 to separate from the casing anchor 148, as illustrated in Fig. 1e. At the top of the stroke, the casing lock 130 (not shown) may be released. After separation, the apparatus 120 is free to continue to advance up causing the casing 110 to expand as necessary. If a hydraulic seal is created between the anchor 148 and the casing 110, the region between the anchor and the sealing mechanism 136 may be pressurized. This pressurized region forces the expansion cone upwardly, thereby causing a radial expansion and plastic deformation of the expandable casing 110. In this manner, in the alternative embodiment, the fluid pressure below the sealing mechanism 136 pulls the expansion cone 140 upwardly through the expandable casing 110. Thus, the use of the tension actuator 134 to pull the expansion cone upwards is no longer necessary.

[0026] At some point (e.g., at the top of the liner), it may become desirable to stop expanding and to inject a hardenable fluidic sealing material such as, for example, cement into the well annulus. To begin the cementing operation, the apparatus 120 may be lowered into the wellbore 100 until the cementing probe 144 couples to the casing anchor 148 as illustrated in Fig. 1f. This coupling opens a bypass flowpath 154 to permit fluidic materials to bypass around the blockage in flow path 126. As a result, the bypass flow path 154 allows for cement or other fluidic materials to flow around the blockage of flow path 126.

[0027] Thus, the cement flows through the interior of the apparatus 120, through the bypass flow path 154, and out through a one-way valve (not shown) into the annulus between the radially expanded tubular member and the wellbore. After the cement has been injected into the annulus, the one way valve may prevent the cement from flowing backwards into the apparatus 120.

[0028] After completing the injection of the cement into the annulus, the drilling pipe may then be pulled upwardly out of the wellbore. The radial expansion and plastic deformation of the expandable tubular member may then be continued by the resumed injection of fluidic material into the apparatus. After the cement has cured, the anchor 148 may be drilled out and another expandable tubular member may then be radially expanded and plastically deformed within the wellbore with the upper end of the other tubular member overlapping with the lower end of the earlier expanded tubular member. In this manner, a mono diameter wellbore casing may be formed that includes a plurality of radially expanded tubular members.

[0029] Turning now to Figs. 2a-2f, there is illustrated an exemplary embodiment of an apparatus 200, which illustrates certain aspects of the apparatus 120 discussed above. At the upper end of the

apparatus 200, there is the gripping device 132. In several exemplary embodiments, the gripping device 132 may be any device capable of engaging the inside surface of the tubular member or casing 110 in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) PCT application no. serial no. PCT/US02/36267, attorney docket no. 25791.88, filed on 11/12/2002, (2) U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/2001, (3) U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/2002, and (4) U.S. provisional patent application serial no. 60/339,013, attorney number attorney docket no. 25791.88, filed on 11/12/2001, the disclosures of which are incorporated herein by reference. In the embodiment as illustrated in Figs. 2a-2f, the gripping device 132 comprises a tubular central mandrel 202 which defines a central passage 203. The central mandrel 202 has an upper end 204a adapted to threadably couple to and receive within an end of the well string 125 in a conventional manner. A tubular retaining sleeve 206 slidably engages the central mandrel 202, such that the retaining sleeve 206 may move longitudinally relative to the central mandrel 202 between an external annular upper flange 205a and an external annular lower flange 205b projecting from the central mandrel 202. A pair of concentric annular recesses in the upper flange 205a form an annular guide flange 209 which fits within the retaining sleeve 206. The retaining sleeve 206 has an internal upper flange 207a and an internal lower flange 207b. The upper flange 207a, the guide flange 209, the external surface of the central mandrel 202 and the internal surface of the retaining sleeve 206 defines an annular upper spring chamber 208a. Similarly, the lower flange 205b, the lower flange 207b, the external surface of the central mandrel 202 and the internal surface of the retaining sleeve 206 defines an annular lower spring chamber 208b. Helical springs 210a and 210b may be disposed within the upper and lower retaining chambers 208a and 208b, respectively to longitudinally position the retaining sleeve 206 relative to the central mandrel 202.

[0030] A plurality of tapered recesses, for example recesses 212a-212d are defined in the external surface of the central mandrel 202. Corresponding to each recess 212a-212d, there is a tapered circular opening, for instance circular openings 214a-214d, through the wall of the retaining sleeve 206. The tapered recesses 212a-212d, the interior surface of the retaining sleeve 206, and the circular openings 214a-214d define retaining chambers 216a-216d, respectively. Hardened gripping elements, such as balls 218a-218d or sprag clutch elements, made from stainless steel or another hardened material, may be positioned within the retaining chambers 216a-216d. In the running configuration illustrated in Figs 2a-2e, the springs 210a and 210b bias the sleeve 206 such that the balls 218a-218d remain in the widest portion of the tapered retaining chambers 216a-216d. In this configuration, the balls do not engage the interior surface of the casing or casing 110.

[0031] An annular pressure chamber 222 may be defined between the bottom of the internal flange 207a of the retaining sleeve 206 and the top of an external annular flange 224. A sealing means, such

as an O-ring or sealing cartridge 211 may provide a seal between the internal flange 207a and the exterior surface of the central mandrel 202. Additionally, a sealing means, such as an O-ring or sealing cartridge 213 may provide a seal between the side of the flange 224 and the exterior of the central mandrel 202. A plurality of radial passages, for instance passages 220a and 220b may be defined with the central mandrel 202 which provides fluid communication between the central passage 203 and the pressure chamber 222. Thus, the pressure of the pressure chamber 222 remains approximately the same as the pressure within the central passage 203. When the pressure of the central passage 203 is large enough to overcome the biasing of the springs 208a and 208b, the pressure chamber 222 expands by driving the upper flange 207 away from the external flange 224. Thus, the upper flange 207 acts like a piston pushing the retaining sleeve 206 in an upwardly direction with respect to the central mandrel 202.

[0032] When the retaining sleeve moves up, the steel balls 218a-218d are forced up into thinner regions of the retaining chambers 216a-216d. A portion of the steel balls 218a-218d, therefore, projects radially through the circular openings 214a-214d. As the steel balls 218a-218d project through the circular openings 214a-214d, they engage the interior surface of the casing 110. The balls 218a-218d grip the interior surface in proportion to the pressure applied to the central passage 203. The balls may create small concave indents that impart a benign compressive stress into the casing 110.

[0033] A lower end 204b of the central mandrel 202 may be adapted to threadably couple to other components or tools, such as the casing lock 130 or the tension actuator 134. In the illustrative embodiment, the lower end 204 is coupled to the tension actuator 134.

[0034] In several exemplary embodiments, the tension actuator 134 may be any device capable of pulling the expansion cone 140 into the casing 110 in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) PCT application no. serial no. PCT/US02/36267, attorney docket no. 25791.88, filed on 11/12/2002, (2) U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/2001, (3) U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/2002, and (4) U.S. provisional patent application serial no. 60/339,013, attorney number attorney docket no. 25791.88, filed on 11/12/2001, the disclosures of which are incorporated herein by reference.

[0035] In the illustrative embodiment, the actuator 134 comprises actuator barrel 250 having a top end 252 adapted to threadably couple to the lower end 204b of the gripping device 132. The actuator barrel 250 defines a longitudinal passage 250a having an internal annular flange 250b at the lower end of the longitudinal passage 250. The lower end of the actuator barrel 250 couples to a connector barrel 254. The connector barrel 254 defines a longitudinal passage 254a having an internal annular flange 254b at the lower end of the longitudinal passage 254a. The lower end of the connector barrel

254 couples to a connector barrel 256. The connector barrel 256 defines a longitudinal passage 256a having an internal annular flange 256b at the lower end of the longitudinal passage 256a.

[0036] A piston tube 260 runs through the passages 250a, 254a, and 256a of the actuator barrel 250 and the connector barrels 254 and 256, respectively. The piston tube 260 may define a longitudinal passage 261. An external annular flange 262a is defined at the top end of the piston tube 260. The outside diameter of the annular flange 262a is slightly smaller than the inside diameter of the longitudinal passage 250a such that the annular flange 262a can slide longitudinally within the longitudinal passage 250a. A sealing means, such as a sealing cartridge 264a creates a seal between the annular flange 262a and the interior surface of the longitudinal passage 250. Similarly a sealing means, such as a sealing cartridge 266a creates a seal between the exterior surface of the piston tube 260 and the flange 254b. An annular pressure chamber 268a may be defined between the bottom of the external flange 262 of the piston tube 260 and the top of the annular flange 250b. Radial tubes 270a and 270b may connect the pressure chamber 268a to the longitudinal passage 261 of the piston tube 260.

[0037] An external annular flange 262b may be defined on the exterior of the piston tube 260. The outside diameter of the annular flange 262b is slightly smaller than the inside diameter of the longitudinal passage 254a such that the annular flange 262b can slide longitudinally within the longitudinal passage 254a. A sealing means, such as a sealing cartridge 264b creates a seal between the annular flange 262b and the interior surface of the longitudinal passage 254a. Similarly a sealing means, such as a sealing cartridge 266b creates a seal between the exterior surface of the piston tube 260 and the flange 254b. An annular pressure chamber 268b may be defined between the bottom of the external flange 262b of the piston tube 260 and the top of the annular flange 254b. Radial tubes 270c and 270d may connect the pressure chamber 268b to the longitudinal passage 261 of the piston tube 260.

[0038] Similarly, an external annular flange 262c may be defined on the exterior of the piston tube 260. The outside diameter of the annular flange 262c is slightly smaller than the inside diameter of the longitudinal passage 256a such that the annular flange 262c can slide longitudinally within the longitudinal passage 256a. Optionally, a sealing means, such as a sealing cartridge 264c creates a seal between the annular flange 262c and the interior surface of the longitudinal passage 256a. Similarly a sealing means, such as a sealing cartridge 266c creates a seal between the exterior surface of the piston tube 260 and the flange 256b. An annular pressure chamber 268c may be defined between the bottom of the external flange 262c of the piston tube 260 and the top of the annular flange 256b. Radial tubes 270e and 270f may connect the pressure chamber 268b to the longitudinal passage 261 of the piston tube 260.

[0039] A lower end 272 of the piston tube may be adapted to be coupled to another component, such as the casing lock 130. Optionally, the casing lock 130 may be positioned above the actuator 130. In

several exemplary embodiments, the casing lock 134 may be any device capable of coupling the apparatus to the casing while the apparatus is being positioned within the wellbore in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) PCT application no. serial no. PCT/US02/36267, attorney docket no. 25791.88, filed on 11/12/2002, (2) U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/2001, (3) U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/2002, and (4) U.S. provisional patent application serial no. 60/339,013, attorney number attorney docket no. 25791.88, filed on 11/12/2001, the disclosures of which are incorporated herein by reference.

[0040] Fig. 2d illustrates an alternative embodiment where a sealing means 136, such as a packer cup assembly may provide a way to create a pressurized zone within the casing 110. In several exemplary embodiments, the sealing means 136 may be any device capable of sealing between differential zones of pressure in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) PCT application no. serial no. PCT/US02/36267, attorney docket no. 25791.88, filed on 11/12/2002, (2) U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/2001, (3) U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/2002, and (4) U.S. provisional patent application serial no. 60/339,013, attorney number attorney docket no. 25791.88, filed on 11/12/2001, the disclosures of which are incorporated herein by reference.

[0041] For instance, an upper packer cup assembly 280 may be coupled to a mandrel 282 proximate the upper end of the mandrel 282. The mandrel 282 may define an longitudinal passage 283. In an exemplary embodiment, a packer cup 284 may be a Guiberson™ packer cup. Optionally, a spacer sleeve (not shown) may mate with, receive, and may be coupled to the mandrel 282 proximate an end of the upper packer cup assembly 280. A lower packer cup assembly 286 may be coupled to the mandrel 282. In an exemplary embodiment, a lower packer cup 286 is a Guiberson™ packer cup. Optionally, a lower spacer sleeve may be coupled to the mandrel 282 to longitudinally position the lower packer assembly 286.

[0042] An expansion cone 140 may be positioned below the sealing means 136. In several exemplary embodiments, the expansion cone 140 may be any device capable of expanding the casing or tubing member 110 within the wellbore 105 in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) PCT application no. serial no. PCT/US02/36267, attorney docket no. 25791.88, filed on 11/12/2002, (2) U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/2001, (3) U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/2002, and (4) U.S. provisional patent application serial no. 60/339,013, attorney number attorney docket no. 25791.88, filed on 11/12/2001, the disclosures of which are incorporated herein by reference.

[0043] In an exemplary embodiment, an adjustable expansion cone may be similar to a conventional adjustable expansion mandrel in that it may be expanded to a larger outside dimension or collapsed to a smaller outside dimension and includes external surfaces for engaging the casing 110 to thereby radially expand and plastically deform the tubular member when the adjustable expansion mandrel is expanded to the larger outside dimension. In an alternative embodiment, the expansion cone 140 may include a rotary adjustable expansion device such as, for example, the commercially available rotary expansion devices of Weatherford International, Inc. In several alternative embodiments, the cross sectional profile of the expansion cone 140 for radial expansion operations may, for example, be an n-sided shape, where n may vary from 2 to infinity, and the side shapes may include straight line segments, arcuate segments, parabolic segments, and/or hyperbolic segments. In several alternative embodiments, the cross sectional profile of the adjustable expansion cone 140 may, for example, be circular, oval, elliptical, and/or multifaceted.

[0044] Alternatively, the expansion cone 140 may be comprised of a plurality of circumferentially spaced apart upper cone segments interleaved among the cam arms of an upper cam spaced around a mandrel 291 defining longitudinal passage 293. In an exemplary embodiment, each upper cone segment includes a first outer surface that defines a hinge groove, a plurality of inner surfaces and a plurality of outer surfaces. In an exemplary embodiment, there may be a combination of arcuate and cylindrical segments. The upper cone segments may be pivotally coupled to an upper cone retainer 290. A plurality of circumferentially spaced apart lower cone segments interleaved among the cam arms of a lower cam. In an exemplary embodiment, each lower cone segment includes a first outer surface that defines a hinge groove, a plurality of inner surfaces and a plurality of outer surfaces. In an exemplary embodiment, there may be a combination of arcuate and cylindrical segments. The lower cone segments may be pivotally coupled to a lower cone retainer 292. Shear pins or another retaining mechanism longitudinally position the lower retainer 292 relative to the upper retainer 290 such that they remain positioned apart during the positioning of the apparatus within the well. In one embodiment, when the apparatus reaches the bottom of the well, the impact shears the shear pins and drives the lower cone retainer toward the upper cone retainer, causing the cone segments to pivot outward in a lateral direction. As the cone segments pivot outward, the diameter of the expansion cone 140 increases. A locking mechanism then locks the cone segments together in an expanded configuration.

[0045] The lower cone retainer 292 receives and may be threadably coupled to an end of a release housing 300 that defines a longitudinal passage 302. A lower end 304 of the release housing 300 defines an external flange 305 adapted to mate into a sleeve 306 in the anchoring device 148. In some exemplary embodiments, a tubular cementing probe 308 may be slidably disposed within the longitudinal passage 302. The cementing probe 308 may be a tubular shaped member which defines a longitudinal passage 310. A top end of the cementing probe 308 has an annular exterior flange or rim

312, the diameter of which is slightly smaller than the interior diameter of the longitudinal passage 302. During operation, an interior annular seat 314 defined within the release housing 300 keeps the flange 312 of cementing probe within the longitudinal passage 302. A lower end of the concrete probe narrows to form a neck 316 which, as will be explained below, is adapted to mate with a collet of the anchoring device 148. During positioning of the apparatus, a probe shear pin 318 longitudinally retains the sliding sleeve within the longitudinal passage 302. Once the cement probe 308 has been extended during operation, however, a probe locking ring 320 may maintain the probe in an extended configuration.

[0046] In the illustrative embodiment, the anchoring device 148 may be an expandable float shoe 340. In some exemplary embodiments, the float shoe 340 may be made out of aluminum or another expandable material which may be relatively easy to drill out. The top end of the float shoe defines a tubular sleeve 342 defining an annular passage 344. The tubular sleeve 342 is adapted to mate within the release housing 300. A sliding sleeve valve 346 is slidably disposed within the longitudinal passage 344.

[0047] The sliding sleeve valve 346 is generally tubular in shape defining a longitudinal passage 348. At a top end of the sliding sleeve valve 346, there is an outwardly protruding flange or rim 350 which circumferentially extends around the top end of sliding sleeve valve 346. Below the rim 350, there is a flexible or top section defining a collet 346a. Below the collet 346a, there is a lower section 346b of the sliding sleeve valve 346. The wall thickness of the collet 346a is narrow relative to the lower section 346b. There are also a predetermined number of longitudinal slots (not shown) extending from the top of the rim 350 through the collet 346a. Preferably these longitudinal slots are equally spaced around the periphery of the collet 346a. The combination of the longitudinal slots and the narrowed wall thickness of the collet 346a allow the diameter of the rim 350 to decrease when the rim 350 is not radially supported by a supporting mechanism. Thus, the rim 350 can be considered "flexible" in that it can contract from a first radial position of a particular diameter to a second radial position of a lesser diameter. In the running configuration illustrated in Fig. 2E, the rim 350 is positioned in an interior recess 352 defined in the sleeve 342. The neck 316 of the cementing probe 308 radially supports rim 350, preventing the rim 350 from slipping out of the recess 352 and thus longitudinally maintains the sliding sleeve valve 346 within the sleeve 342. A side port 354 may be defined within the side wall of the lower section 346b.

[0048] In several exemplary embodiments, there is an annular seat 355 positioned within the longitudinal passage 344 of the float shoe 340. The annular seat 355 is adapted to sealingly couple to a plug. The plug may be any conventional plug, such as a drill pipe dart or phenolic ball that would provide a hydraulic seal upon reaching the annular seat 355. The sleeve 342 of the float shoe 340 increases in diameter to accommodate a bypass passage 356. The bypass passage 356 defines a passage that connects the portion of the longitudinal passage 344 above the seat 355 to a portion of

the longitudinal passage 344 below the seat 356, thereby creating a "bypass" around the seat 356. In the running position illustrated in Figs. 2a-2e, an entrance port 356a of the bypass passage 356 is blocked by the sliding sleeve valve 346.

[0049] Positioned below the annular seat 355 is a one-way valve 358. In several exemplary embodiments, the one way valve 358 may be a float valve assembly which allows for a fluid to flow in a downward direction, but prevents fluid to flow in an upward direction. The one-way valve 358 opens into an longitudinal passage 360. A sleeve, such as a dog locking sleeve 362 may be slidingly disposed within the longitudinal passage 360. A shear pin 364 maintains the relative position of the dog locking sleeve relative to the float shoe 340 such that a lower end 368 of the dog locking sleeve is disposed below the float shoe 340. At the top end of the dog locking sleeve 362, there is an external flange 366 adapted such that an upward movement by the external flange 366 "expands" or pushes out a plurality of dogs 370 through a plurality of radial side openings 372 defined in the float shoe 340. In several alternative embodiments, the dogs 370 or expansion mechanism 150 within the float shoe 340 may be replaced by a shoulder on the float shoe for engaging the end of the radially expanded tubular member.

[0050] In an exemplary embodiment, during operation of the apparatus 200, as illustrated in Figs. 2a-2e, the apparatus may be initially positioned in the wellbore 100, partially within the casing 110, with the expansion cone 140, the cementing probe 144, and the float shoe 340 positioned outside the casing. In this manner, fluidic materials within the interior of the apparatus 200 may pass through the longitudinal passages 203, 250a, 261, 283, 293, 302, 310, 344, 348, and 360 out of the apparatus through the float valve 358, into the annulus between the apparatus 200 and the casing 110 thereby preventing over pressurization of the annulus.

[0051] Referring now to Figs. 3a-3e, there is illustrated the apparatus 200 positioned at the bottom of the wellbore 100. When the apparatus 200 contacts with the bottom of the wellbore 100, the dog locking sleeve 368 is driven up into the float shoe 340, shearing the shear pin 360. The upward movement of the locking sleeve 368 forces the dogs 370 through the side openings 372, where a locking mechanism prevents their retraction.

[0052] In an alternative embodiment of the expansion cone, the force of impact with the bottom of the well shears the retaining mechanism, forcing the lower expansion cone retainer 292 towards the upper expansion cone retainer 290. The interleaved cone segments pivot outward in a lateral direction on top of one another. As the cone segments pivot outward, the diameter of the expansion cone 140 increases. A locking mechanism then locks the upper cone segments in place. Thus, the expansion cone may expand to a diameter that is greater than the interior diameter of the casing 110.

[0053] Referring now to Figs. 4a-4f, there is illustrated the apparatus 200 when a plug, such as a ball 374 is then injected into the apparatus with the fluidic material through the passages 203, 250a, 261, 283, 293, 302, 310, 344 and 348 until the dart is positioned and seated on the annular seat 355 in the

float shoe 340. As a result of the positioning of the ball 374 in the passage 344 of the float shoe 340, the passage 344 of the float shoe is thereby closed.

[0054] The fluidic material is then injected into the apparatus thereby increasing the operating pressure within the passages 203, 250a, 261, 283, 293, 302, 310, 344 and 348. Furthermore, the continued injection of the fluidic material into the apparatus 200 causes the fluidic material to pass through the radial passages 220a and 220b, into the annular pressure chamber 222 of the gripping device 132. When the pressure of the central passage 203 is large enough to overcome the biasing of the springs 208a and 208b, the pressure chamber 222 expands by driving the upper flange 207 away from the external flange 224. Thus, the upper flange 207a acts like a piston pushing the retaining sleeve 206 in an upwardly direction with respect to the central mandrel 202. When the retaining sleeve moves up, the steel balls 218a-218d are forced up into thinner regions of the retaining chambers 216a-216d. A portion of the steel balls 218a-218d, therefore, projects radially through the circular openings 214a-214d. As the steel balls 218a-218d project through the circular openings 214a-214d, they engage the interior surface of the casing 110.

[0055] The fluidic material is then injected into the apparatus thereby increasing the operating pressure within the passages 203, 250a, 261, 283, 293, 302, 310, 344 and 348. Furthermore, the continued injection of the fluidic material into the apparatus 200 also causes the fluidic material to pass through the radial tubes 270a through 270f, of the piston tube 260 into an annular pressure chambers 268, 268a, and 268b, respectively.

[0056] The pressurization of the annular pressure chambers, 268a, 268b, and 268c then cause the piston flanges 262a, 262b, 262c to be displaced upwardly relative to the casing 100. As a result, the upper packer cup assembly 280, the lower packer cup assembly 286, expansion cone 140, the release housing 300, the cementing probe 308, and the float shoe 340 are displaced upwardly relative to the casing 110.

[0057] The continued injection of the fluidic material into the apparatus 200 continues to pressurize annular pressure chambers, 268a, 268b, and 268c. The further upward displacement of the piston flanges 262a, 262b, 262c in turn displaces the expansion cone 140 upwardly relative to the casing 110. As a result, the expansion cone 140 radially expands and plastically deforms a portion of the casing 110.

[0058] Referring to Figs. 5a-5f, during the continued injection of the fluidic material, the expansion cone 140 will continue to be displaced upwardly relative to the casing 110 thereby continuing to radially expand and plastically deform the casing until the locking dogs 370a-370b engage the lower end of the casing 110. The continued upward movement of the expansion cone 140, cement probe 308, and release housing 300 causes the release housing 300 to move longitudinally upward - out of the sleeve 306 of the float shoe 340. The external flange 305 of the release housing 300 causes the sleeve 306 to radially expand against the casing 110. In some embodiments, this radial expansion of

the sleeve 306 also causes an expansion and plastic deformation of a portion of the casing 110 which may also hydraulically seal the sleeve 306 to the casing 110. Optionally, an elastomeric sealing material may be applied to the exterior of the sleeve 306 to create a seal between the sleeve 306 and the casing 110.

[0059] Referring to Figs. 6a to 6e, The continued upward movement of the expansion cone 140, cement probe 308, and release housing 300 causes the probe shear pin 318 to shear. The force on the cement probe 308 pulls the probe downward until the external flange 312 impacts the seat 314 defined with the passage 302 preventing further movement of the cement probe. A probe lock ring 313 disposed on the exterior surface of the concrete probe contacts a downward facing seat 315, thereby "locking" the concrete probe in place. The continued upward movement of the cement probe 308 causes the cement probe 308 to separate from the float shoe 340. At the top of the stroke of the tension actuator 134, the casing lock 130 may be released. After separation, the apparatus 200 is free to continue to advance up causing the casing 110 to expand as necessary. Because there is an hydraulic seal between the sleeve 306 and the casing 110, the region between the float shoe 340 and the packer cup assemblies 280 and 286 may be pressurized. This pressurized region forces the expansion cone 140 upwardly, thereby causing a continued radial expansion and plastic deformation of the expandable casing 110. In this manner, the fluid pressure below the packer cup assemblies 280 and 286 pulls the expansion cone 140 upwardly through the expandable casing 110. Thus, the use of the tension actuator 134 to pull the expansion cone upwards is no longer necessary.

[0060] At some point (e.g., at the top of the liner), it may become desirable to stop expanding and to inject a hardenable fluidic sealing material such as, for example, cement into the well annulus. Referring to Figs. 7a to 7f, to begin the cementing operation, the apparatus 200 may be lowered into the wellbore 100 until the neck 316 of the cementing probe 308 impacts the collet 346a forcing the rim 350 of the collet from the recess 352, which allows the sliding sleeve valve 346 to move downward until the sliding sleeve valve impacts an upward facing seat 345 in the passage 344. In this position, the sideport 354 is aligned with the opening of the bypass flowpath 356 to permit fluidic materials to bypass around the ball in the passage 344. As a result, the bypass flow path 356 allows for cement or other fluidic materials to flow around the ball.

[0061] Thus, the cement may flow through the through the bypass flow path 356, and out through the one-way valve 358 into the annulus between the radially expanded tubular member and the wellbore. After the cement has been injected into the annulus, the one way valve may prevent the cement from flowing backwards into the flowpath 356.

[0062] After completing the injection of the cement into the annulus, the drilling pipe may then be pulled upwardly out of the wellbore. The radial expansion and plastic deformation of the expandable tubular member may then be continued by the resumed injection of fluidic material into the apparatus. After the cement has cured, the float shoe 340 may be drilled out and another expandable tubular

member may then be radially expanded and plastically deformed within the wellbore with the upper end of the other tubular member overlapping with the lower end of the earlier expanded tubular member. In this manner, a mono diameter wellbore casing may be formed that includes a plurality of radially expanded tubular members.

[0063] In several alternative embodiments, a packer may be used instead of the float shoe 340 to couple the end of the casing to the apparatus. Referring to Figs. 8a to 8e, an alternative embodiment, an apparatus 500 for forming a mono diameter wellbore casing 502 provides a one step monobore wellbore casing radial expansion system. The one step monobore system can also be used as a cased or open hole radial expansion system, or an open hole cladding system where an expandable casing is clad against a formation in open hole.

[0064] In an exemplary embodiment, the apparatus 500 includes an expansion assembly 504 and a packer 506. The expansion assembly 504 includes, among other things, a safety sub 508, a gripping device 510, a casing lock device 512, a force multiplier or tension actuator 514, an expansion cone 516, a packer setting sleeve 518, an internal sleeve 520 and a stinger 522.

[0065] In an exemplary embodiment, the safety sub 508 allows a quick connection and disconnection of the drill string to and from the expansion system.

[0066] In several exemplary embodiments, the gripping device 510 may be any device capable of engaging the inside surface of the tubular member or casing 502 in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) PCT application no. serial no. PCT/US02/36267, attorney docket no. 25791.88, filed on 11/12/2002, (2) U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/2001, (3) U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/2002, and (4) U.S. provisional patent application serial no. 60/339,013, attorney number attorney docket no. 25791.88, filed on 11/12/2001, the disclosures of which are incorporated herein by reference. In the embodiment as illustrated in Figs. 8a-8f, the gripping device 510 comprises hydraulic slips 510a-510c are isolated from internal pressure by a rupture disc 524. In an exemplary embodiment, a packer cup 526 acts as a check valve to allow external pressure to equalize behind the hydraulic slips 510a-510c when in a running configuration, but holds internal pressure when the rupture disc is ruptured. In an exemplary embodiment, the hydraulic slips 510a-510c are actuated by rupturing the rupture disc 524 with internal pressure. In an exemplary embodiment, the internal pressure then acts on the hydraulic slips 510a-510c, moving them out against the internal diameter of the expandable casing 502. The hydraulic slips 510a-510c thereby provide an anchor for the tension actuator to pull the expansion cone 504 against and expand the expandable casing. When the internal pressure is released, the hydraulic slips 510a-510c retract away from the internal diameter of the expandable casing 502.

[0067] In an exemplary embodiment, a casing lock 512 holds the weight of the expandable casing string as it is run in the well. In several exemplary embodiments, the casing lock 512 may be any device capable of coupling the apparatus to the casing while the apparatus is being positioned within the wellbore in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) PCT application no. serial no. PCT/US02/36267, attorney docket no. 25791.88, filed on 11/12/2002, (2) U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/2001, (3) U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/2002, and (4) U.S. provisional patent application serial no. 60/339,013, attorney number attorney docket no. 25791.88, filed on 11/12/2001, the disclosures of which are incorporated herein by reference.

[0068] In the illustrative embodiment, casing lock dogs 530 fit in upsets formed in the internal diameter of the expandable casing and are held in place with a retaining sleeve 532. When the retaining sleeve 532 is shifted by the tension actuator 514, the dogs 530 retract and the expansion 504 is released from the expandable casing 502.

[0069] In several exemplary embodiments, the tension actuator 514 may be any device capable of pulling the expansion cone 140 into the casing 110 in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) PCT application no. serial no. PCT/US02/36267, attorney docket no. 25791.88, filed on 11/12/2002, (2) U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/2001, (3) U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/2002, and (4) U.S. provisional patent application serial no. 60/339,013, attorney number attorney docket no. 25791.88, filed on 11/12/2001, the disclosures of which are incorporated herein by reference. The tension actuator 514 may also be similar to the tension actuator 134 described above.

[0070] In an exemplary embodiment, the tension actuator 514 provides several stages of differential area for internal pressure to act upon and thereby provide an upward force to the expansion cone 504 to thereby expand the expandable casing 502. The tension actuator 514 may be used to initially expand the expandable casing 502 and to pull the packer 506 into the radially expanded casing 502. The tension actuator 514 may be used at any time during radial expansion process when the hydraulic slips 510a-510b are actuated to provide additional upward force to the expansion cone. In an exemplary embodiment, the tension actuator 514 may be used to assist in the radial expansion process when the portion of the expandable casing that overlaps with another casing is radially expanded and plastically deformed.

[0071] In several exemplary embodiments, the expansion cone 504 be any device capable of expanding the casing or tubing member 110 within the wellbore 105 in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) PCT application no. serial no. PCT/US02/36267, attorney docket no. 25791.88, filed on 11/12/2002, (2)

U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/2001, (3) U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/2002, and (4) U.S. provisional patent application serial no. 60/339,013, attorney number attorney docket no. 25791.88, filed on 11/12/2001, the disclosures of which are incorporated herein by reference.. Thus, the expansion cone 516 may be an adjustable expandable expansion cone, or it may be expandable or non-expandable for use in cased or open hole expansion systems or open hole clad systems..

[0072] In an exemplary embodiment, an internal sleeve 534 blocks ports 536 which lead from the internal passage 528 to the packer setting sleeve 538. In an exemplary embodiment, the internal sleeve 534 may be moved away from the ports 536 by the tension actuator 514 at the end of the tension actuator stroke to allow internal pressure to act on the packer setting sleeve 538 and thereby set the packer 506 in the expanded casing 502. Thus, in an exemplary embodiment, the packer setting sleeve 538 is moved downwardly against the packer 506 to set the packer by internal pressure.

[0073] In an exemplary embodiment, the packer 506 may be a fas drill packer which is a composite drillable packer that is set in the expanded casing and contains the expansion pressure. The fas drill packer includes an internal pressure balanced sliding sleeve valve 540 which is used to open and close fluid ports 542. The sleeve valve 540 has two external seals which seal against the internal diameter of the fas drill packer and isolate fluid ports in the fas drill packer when the sleeve valve is in the up position. When the sleeve valve is moved downwardly, ports 544 in the sleeve valve 540 align with ports 542 in the fas drill packer and allow fluid to be displaced into a bypass passage 546 in the fas drill packer. Collets at the top of the sleeve valve fit in an internal groove provided in the internal diameter of the fas drill packer when the sleeve valve is in the up position and allow the end of the stinger to pass and shoulder against the sleeve valve. When a stinger 548 pushes the sleeve valve 540 downwardly to open the ports 542, the collets are pulled out of the groove and retract inward into an external undercut on the bottom of the stinger 548.

[0074] When the stinger 548 is moved up to close the ports 542, a lower shoulder on the external undercut contacts the inward retracted collets and pulls the sliding sleeve valve 540 upwardly until the collets expand out into the internal groove. The sleeve valve 540 is operated with a stinger 548 attached to the expansion assembly 504. Below the sleeve valve 540 are two ball seats 550a and 550b with a rupture disc 552 in between. The bypass passage 546 connects the ports 542 covered by the sleeve valve, the rupture disc ports 554, and ports 556 positioned below the bottom ball seat.

[0075] A check valve 558 may be disposed at the bottom of the fas drill packer. Other types of commercially available drillable packers may also be used, such as, for example, the EZ Drill. Additionally, for open and cased hole cladding systems where cement is not going to be used, retrievable packers can be used and retrieved after expansion instead of drilled.

[0076] In an exemplary embodiment, the stinger 548 may be attached to the expansion assembly 504 and includes an external seal 560 which seals against the inside diameter of the fast drill packer. At the bottom end of the stinger is an external undercut which is used to close the sliding sleeve valve.

[0077] Turning now to Figs. 9a-9e, which illustrates some aspects of the operation of the apparatus 500. In Fig. 9a, the expansion assembly 504 is run through the casing 502 until the packer 506 is in open hole beyond the casing.

[0078] A first plug, which may be a ball or a dart, may be dropped to the plug seat 550a in the packer central passage 528. Continued pumping of fluids causes the internal pressure to be increased. As described above with reference to Figs. 1a to 7f, the pressure actuates the tension actuator 514 which pulls the expansion cone 516 up against the bottom of the casing 510.

[0079] The expansion cone 516 expands in size and then expands the expandable casing 502, pulling the packer 506 upwardly along with it. Near the end of the tension actuator stroke, the packer 506 is positioned in the expanded casing and the lower end of the tension actuator shoulders against the internal sleeve 520, shifting it downward. As a result, the ports 536 open allowing fluidic communication from the central passage 528 to the packer setting sleeve 538. The internal pressure then causes the setting sleeve 538 to move down, which pushes against and sets the packer 506.

[0080] The tension actuator 514 then pulls against a connecting mechanism, such as a plurality of shear pins, connecting the packer 506 to the expansion assembly 504 until they shear.

[0081] At the end of the tension actuator stroke, an upper end 562 of the tension actuator 514 shoulders against the dog retaining sleeve 532 and moves it upward, releasing the dogs 530 and unlocking the expansion assembly 504 from the casing 502.

[0082] Continued injection of the fluidic material into the apparatus 500 causes an increase in the internal pressure in the central passage 528. The increased pressure ruptures the rupture disc 554, which allows the fluid to flow into the bypass passage 546. The casing 502 can now be run to the bottom of the well.

[0083] Once the casing has reached the bottom of the well, a second plug may be dropped. The second plug is sized to sealingly fit the second plug seat 550b. The second plug stops circulation through the bypass passage 546. Continued injection of fluid increases the internal pressure in the central passage 528 so that the casing expansion can be partially or completely continued, or the expansion assembly can be set down to open the sliding sleeve valve to circulate mud or displacement. Picking back up on the expansion assembly 504 will close the sliding sleeve valve. At any point during expansion, the expansion assembly 504 can be set down on the packer 506 to open the sliding sleeve valve 540 to continue circulation.

[0084] Once the expansion assembly 504 reaches an overlap section of the expandable casing 502, the expansion pressure increases until the upper rupture disc 524 ruptures. The hydraulic slips 510a-510c then move out against the internal diameter of the expandable casing 502, providing an anchor

for the tension actuator to pull the expansion cone against. When the tension actuator 514 reaches the end of its stroke, the internal pressure is released, the hydraulic slips 510a-510c retract, and the tension actuator 514 is extended for another stroke. In an exemplary embodiment, the hydraulic slips 510a-510c may be designed to not only contact the unexpanded casing, but will also extend out far enough to contact the previously expanded casing string at the final expansion stroke.

[0085] After the expansion assembly 504 is pulled out of the well, the packer 506 may be drilled out and another section of hole may be drilled. An identical expansion system is then run and expanded to the same ID as the previous string.

[0086] It is understood that variations may be made in the foregoing without departing from the scope of the invention. For example, the teachings of the present illustrative embodiments may be used to provide a wellbore casing, a pipeline, or a structural support. Furthermore, the elements and teachings of the various illustrative embodiments may be combined in whole or in part in some or all of the illustrative embodiments.

[0087] It is understood that variations may be made in the foregoing without departing from the scope of the invention. For example, the teachings of the present illustrative embodiments may be used to provide a wellbore casing, a pipeline, or a structural support. Furthermore, the elements and teachings of the various illustrative embodiments may be combined in whole or in part in some or all of the illustrative embodiments.

[0088] Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

Claims

What is claimed is:

1. An apparatus for radially expanding and plastically deforming an expandable tubular member, comprising:

an anchoring mechanism adapted to mate with an end of the expandable tubular member;

a tubular member releasibly coupled to the anchoring mechanism,

an adjustable expansion mandrel coupled to the tubular member adapted to be controllably expanded to a larger outside dimension for radial expansion of the expandable tubular member or collapsed to a smaller outside dimension;

an actuator coupled to the adjustable expansion mandrel adapted to controllably longitudinally displace the adjustable expansion mandrel relative to the expandable tubular member; and

a gripping device coupled to the locking adapted to controllably engage the expandable tubular member.

2. The apparatus of claim 1 further comprising a locking device coupled to the actuator adapted to controllably engage the expandable tubular member.

3. The apparatus of claim 1 further comprising a sealing device for sealingly engaging the expandable tubular member adapted to define a pressure chamber above the adjustable expansion mandrel during radial expansion of the expandable tubular member.

4. The apparatus of claim 1 wherein the gripping device comprises:

a tubular mandrel having a plurality of tapered grooves defined on an exterior surface of the tubular mandrel,

a retaining sleeve coupled to the tubular mandrel and adapted to slidingly move longitudinally with respect to the tubular mandrel, the retaining sleeve having a plurality of openings,

a plurality of gripping elements positioned within the tapered grooves, wherein when the retaining sleeve is in a first longitudinal configuration, portions of the gripping elements protrude through the plurality of openings, and when the retaining sleeve is in a second longitudinal configuration, portions of the the gripping elements do not protrude through plurality of tapered openings.

5. The apparatus of claim 1 wherein the anchoring device is a float shoe, comprising:

an expandable sleeve adapted to mate with the tubular member, wherein the tubular member is adapted to controllably expand the expandable sleeve to a larger outside dimension for radial expansion of the expandable sleeve to the expandable tubular member.

6. The apparatus of claim 5 wherein the anchoring device comprises:

a first passage,

a second passage,

a seat within the first passage adapted to receive a plug,

a sliding valve disposed within the first passage, adapted to direct flow from the first passage to the second passage, and

a one-way valve coupled to the first and second passages.

7. The apparatus of claim 1 wherein the anchoring mechanism is a packer.

8. The apparatus of claim 1 wherein the packer is hydraulically actuated.

9. The apparatus of claim 1 wherein the packer comprises:

a first passage,

a second passage,

a first seat within the first passage adapted to receive a plug, and

a sliding valve disposed within the first passage, adapted to direct flow from the first passage to the second passage.

10. A method for radially expanding and plastically deforming an expandable tubular member within a borehole, comprising:

positioning an adjustable expansion mandrel, an anchoring device, and a coupling mechanism below the expandable tubular member such that the anchoring device contacts a bottom of the borehole,

increasing the outside dimension of the adjustable expansion mandrel; and

displacing the adjustable expansion mandrel upwardly relative to the expandable tubular member to radially expand and plastically deform portions of the expandable tubular member,

displacing the anchoring device upwardly relative to the expandable tubular member such that the anchoring device contacts the bottom of the expandable tubular member,

coupling the anchoring device to the bottom of the casing,

uncoupling the expansion mandrel from the anchoring device, and

displacing the adjustable expansion mandrel upwardly relative to the expandable tubular member n times to radially expand and plastically deform n portions of the expandable tubular member.

11. The method of claim 10, further comprising:

lowering the adjustable expansion mandrel to couple the expansion mandrel to the anchoring device, and

cementing the borehole, wherein the cementing flows through a flow path located in the anchoring device.

12. The method of claim 10 further comprising expanding an expansion device coupled to the anchoring device such that the anchoring device couples to the casing.

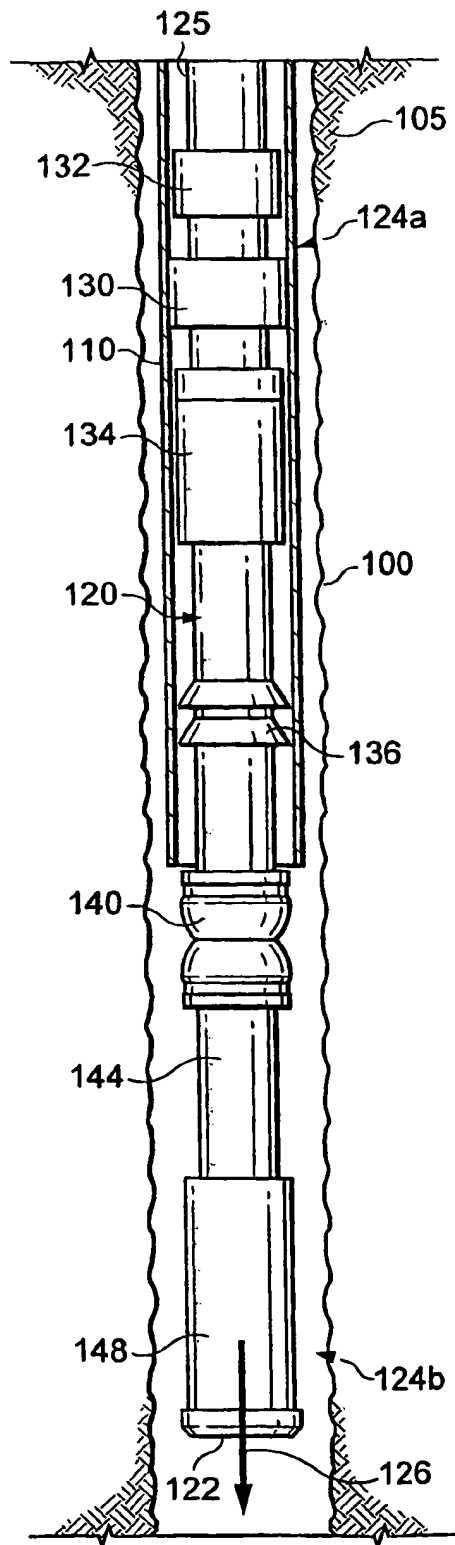


Fig. 1a

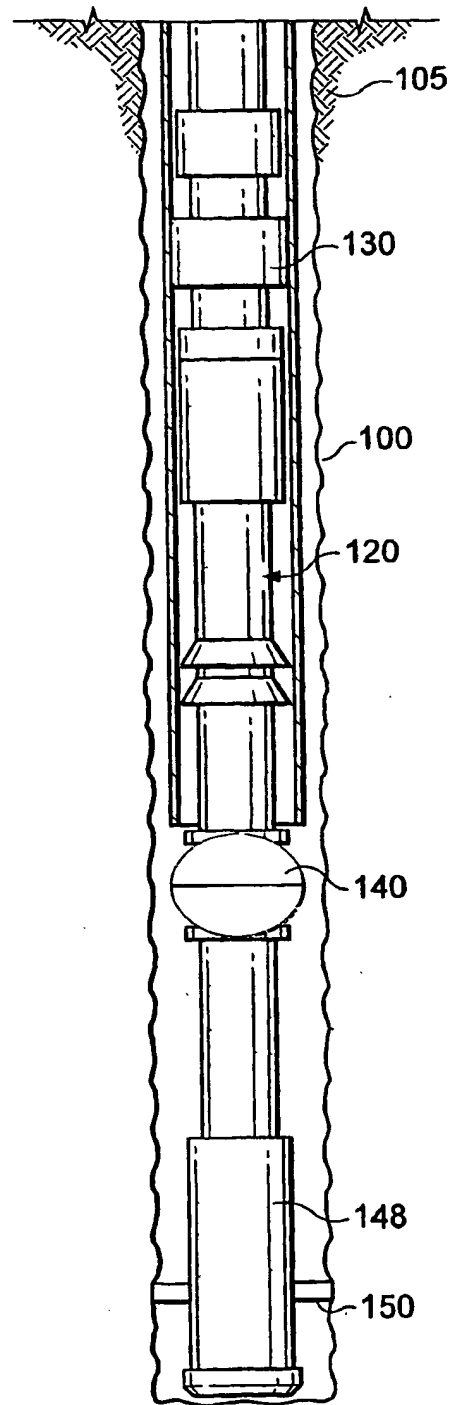


Fig. 1b

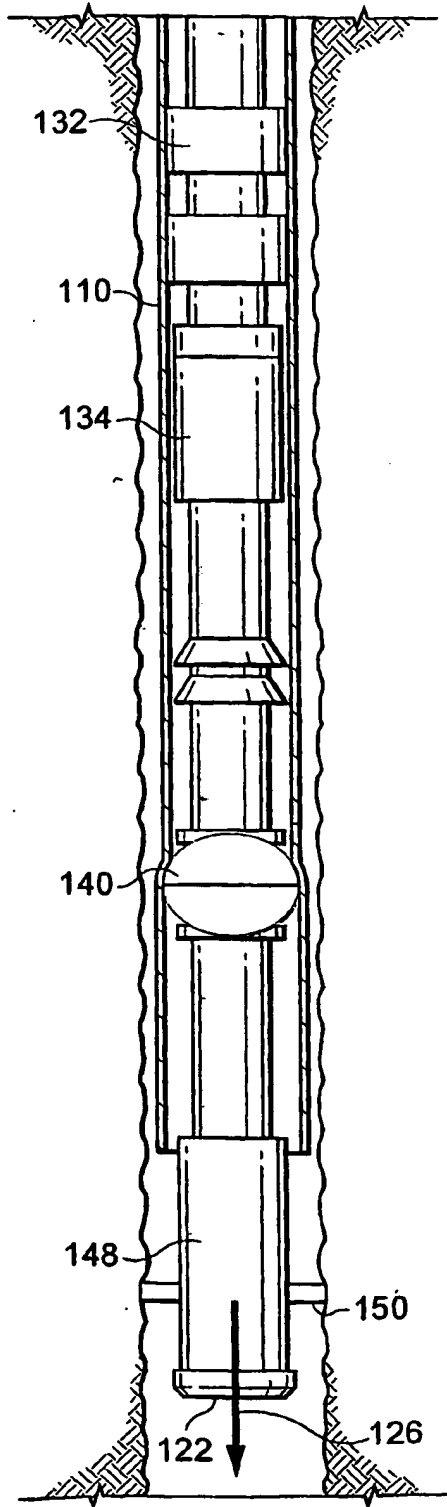


Fig. 1c

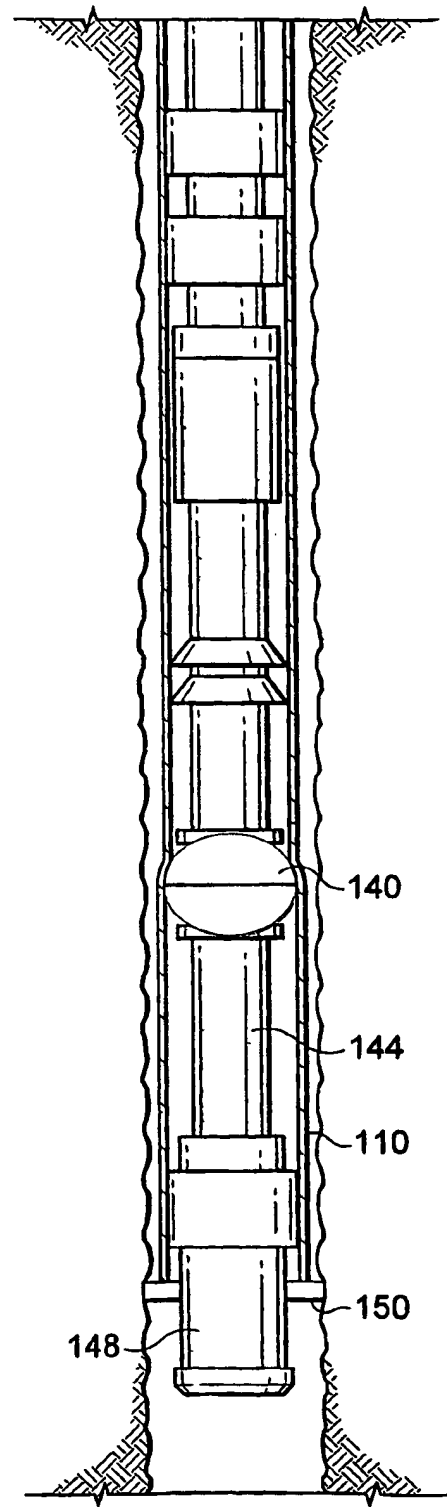


Fig. 1d

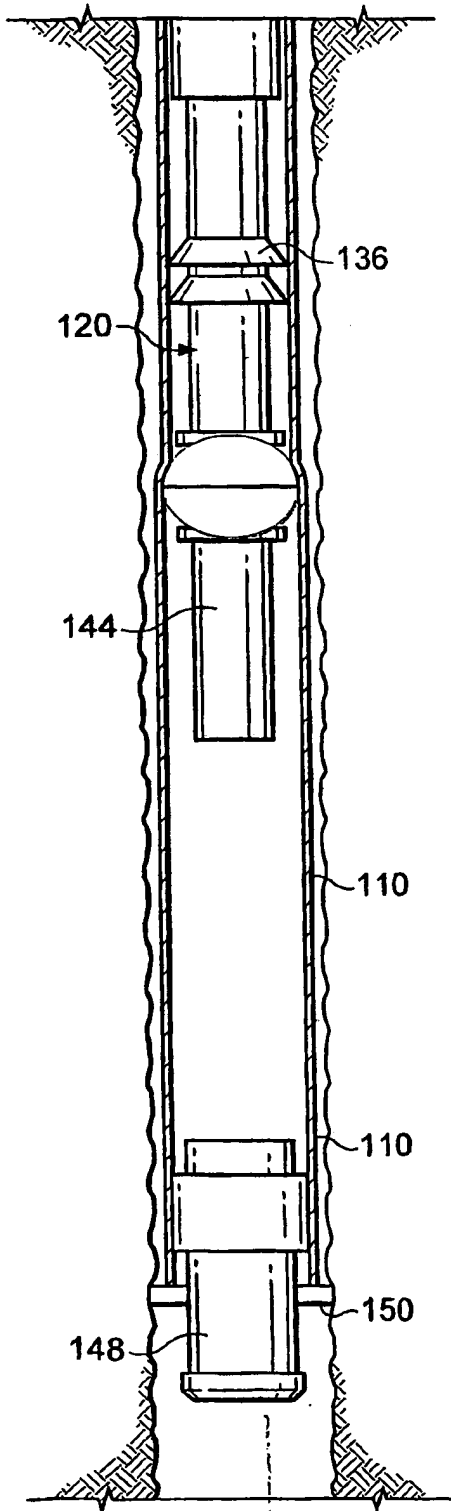


Fig. 1e

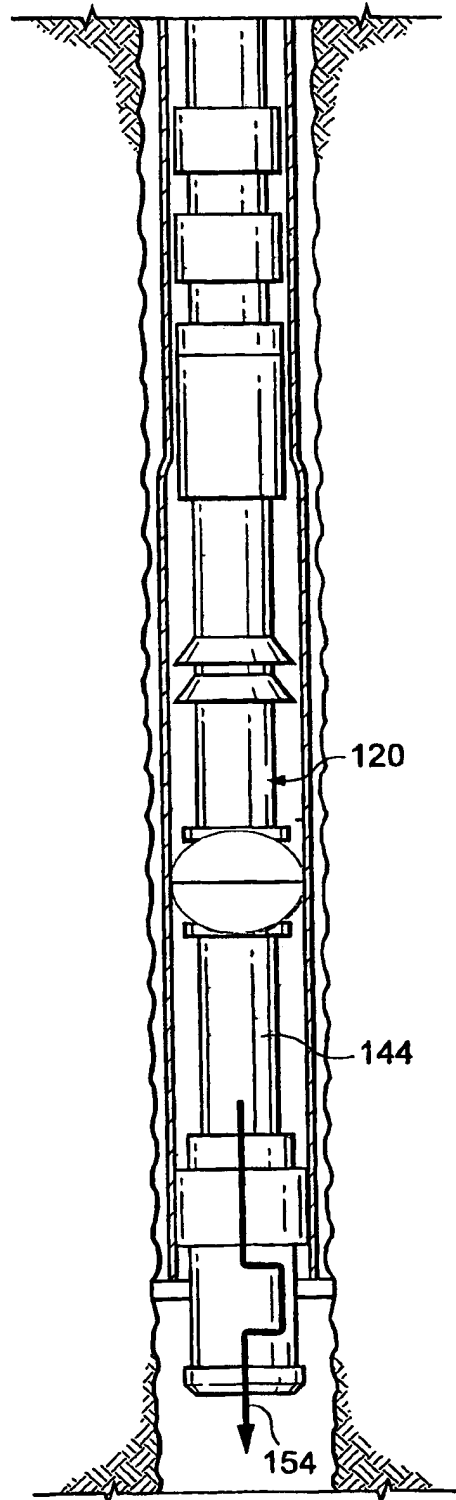


Fig. 1f

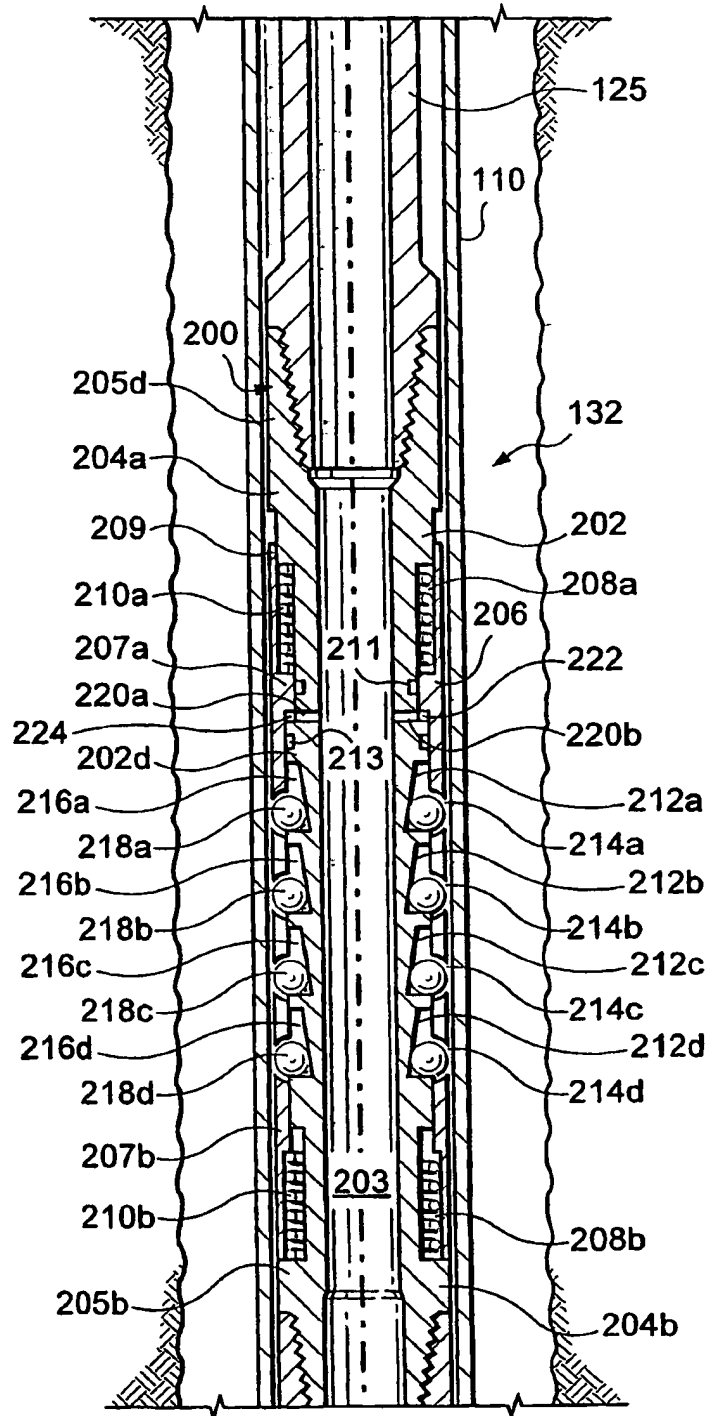
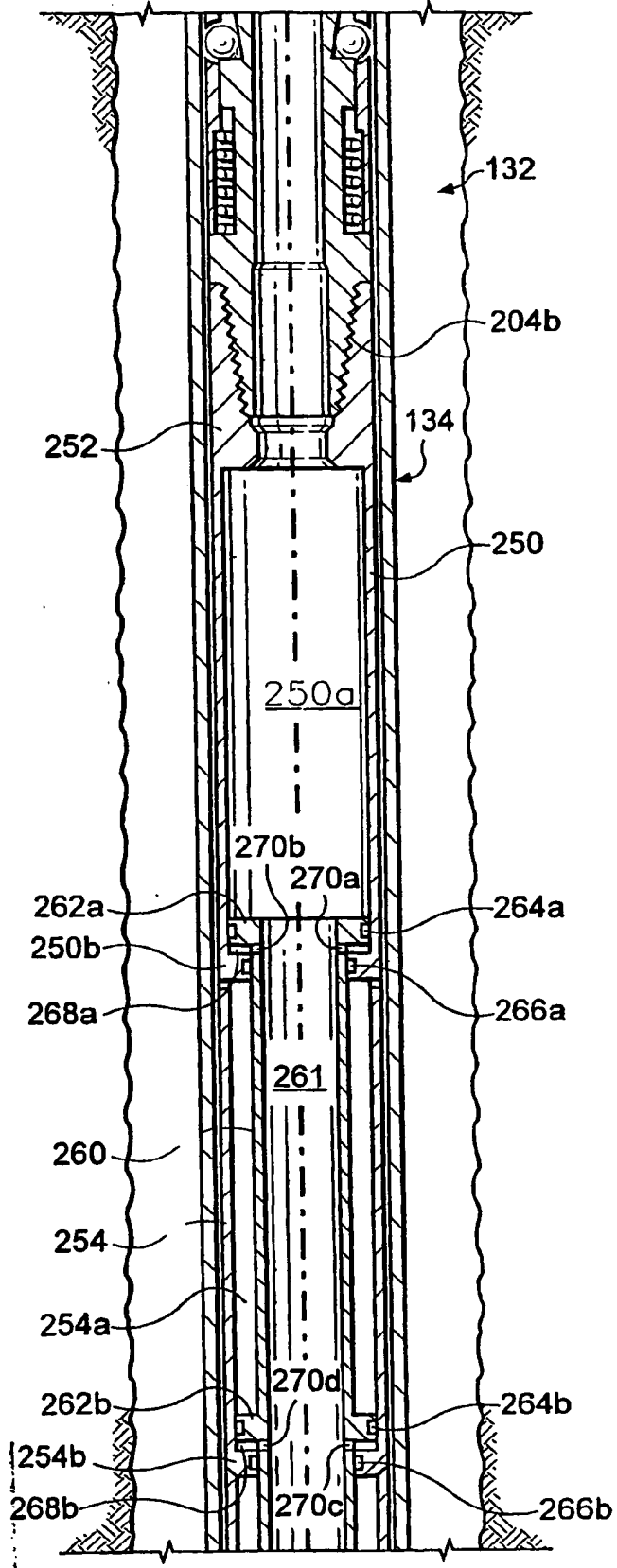
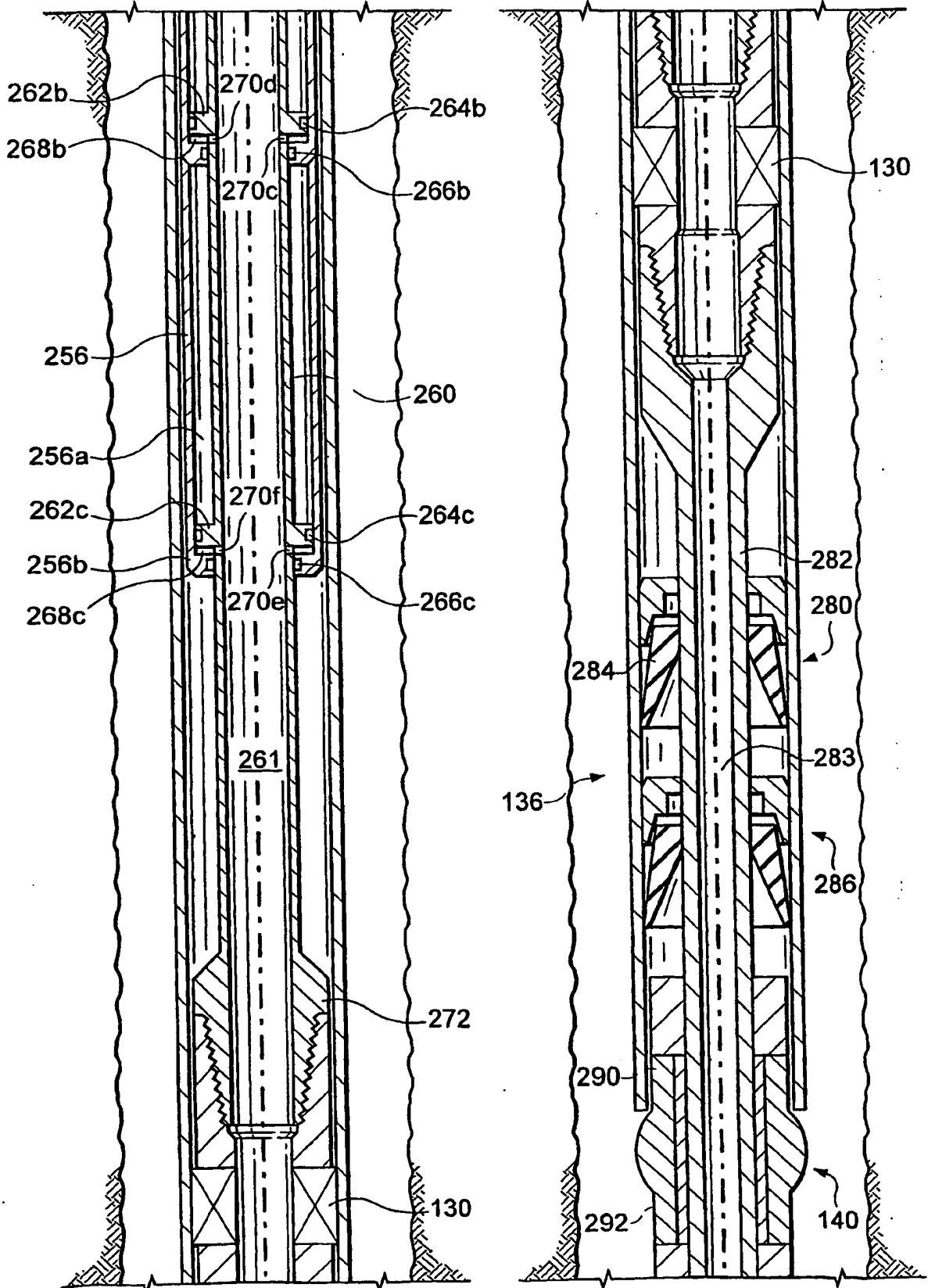


Fig. 2a

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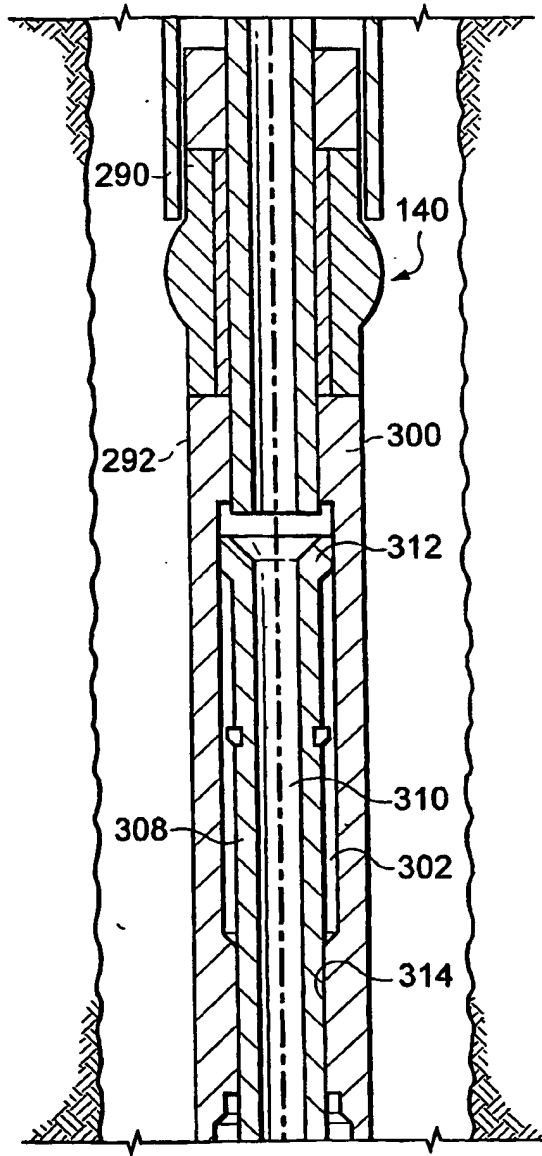
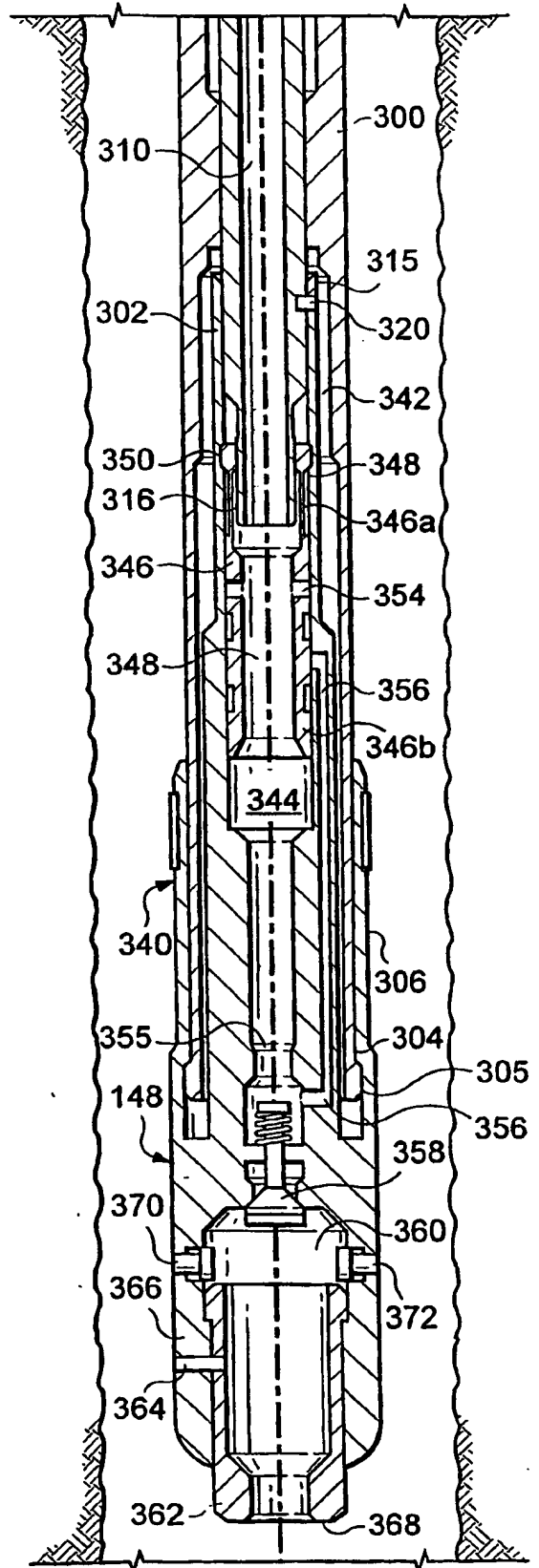
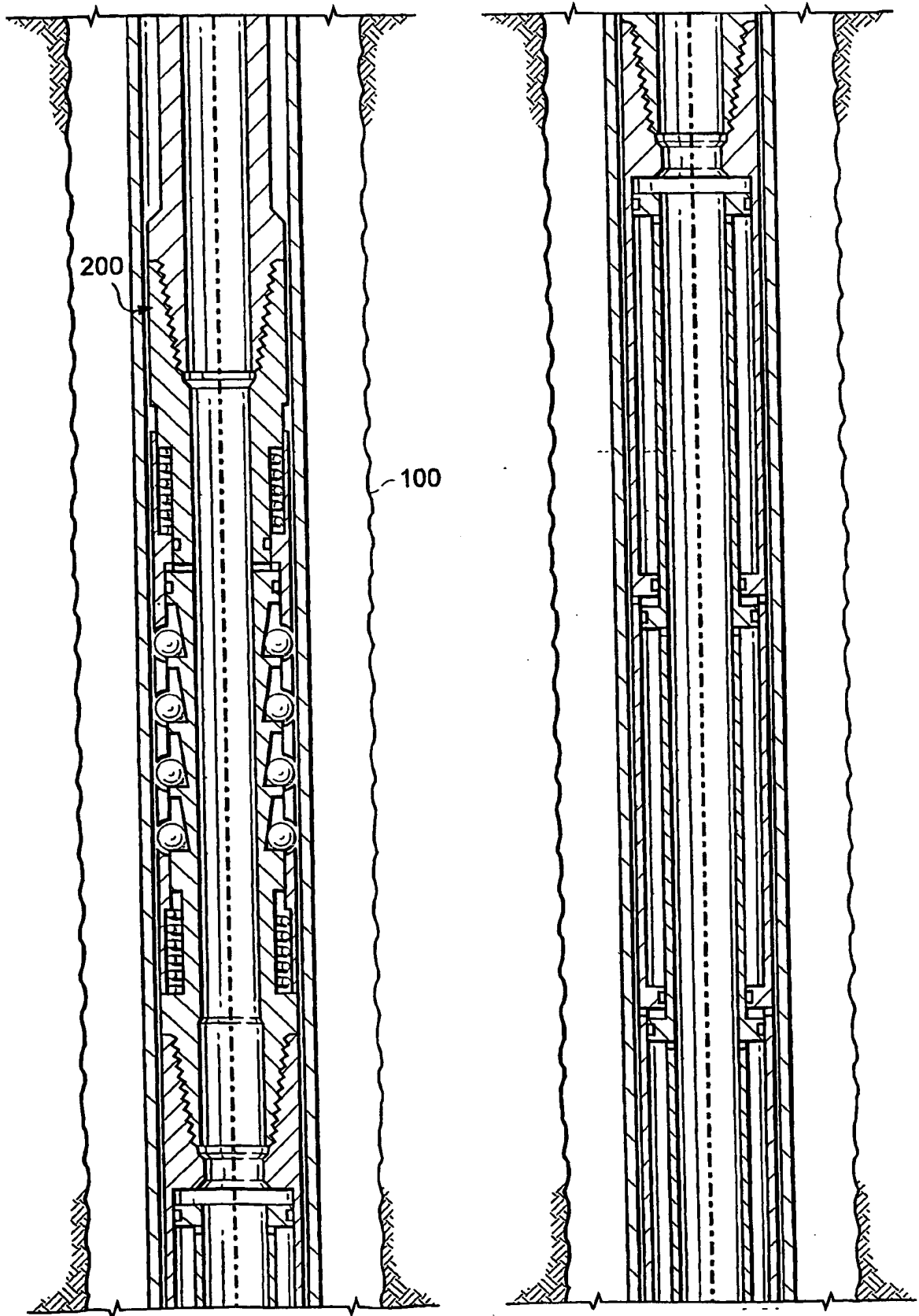


Fig. 2e



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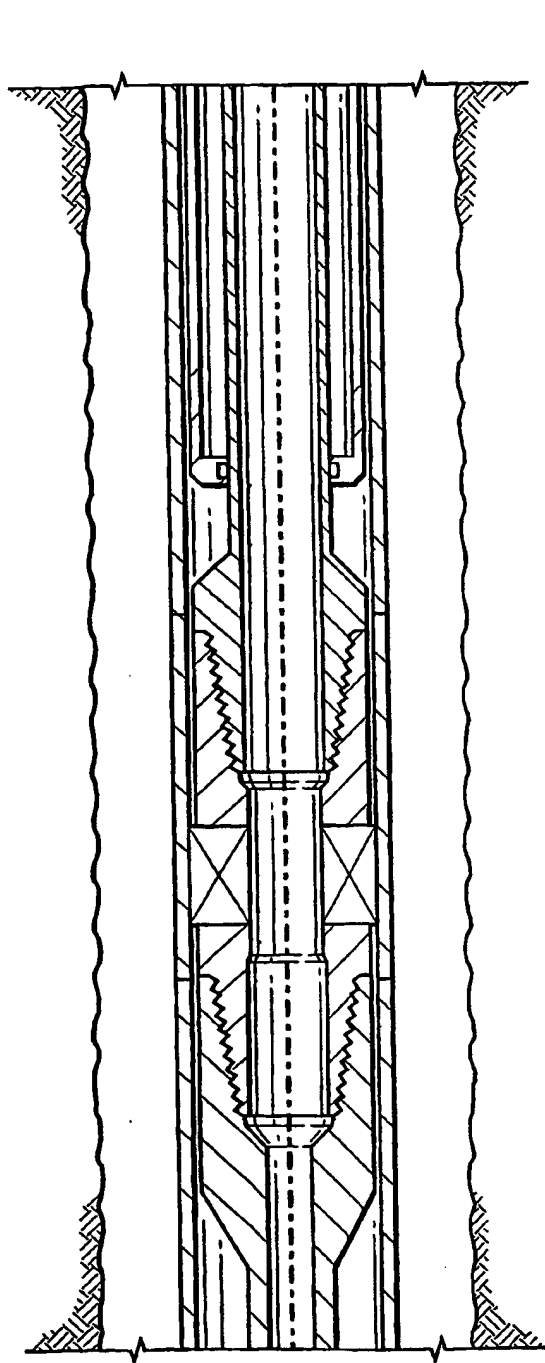
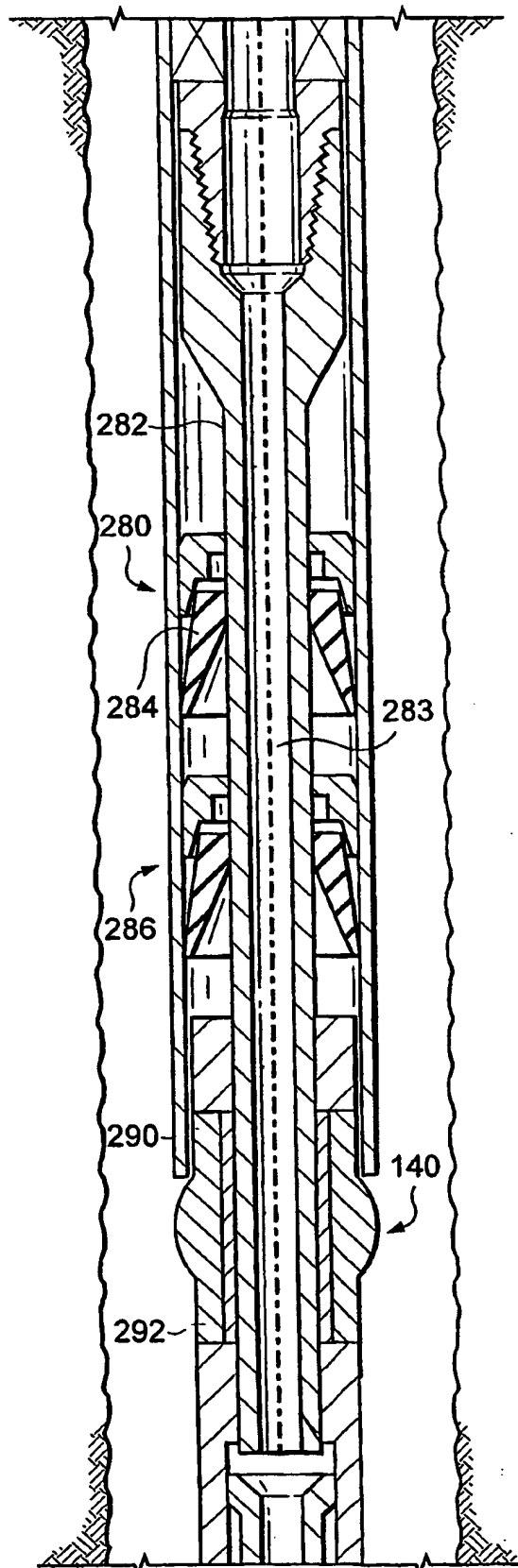


Fig. 3c



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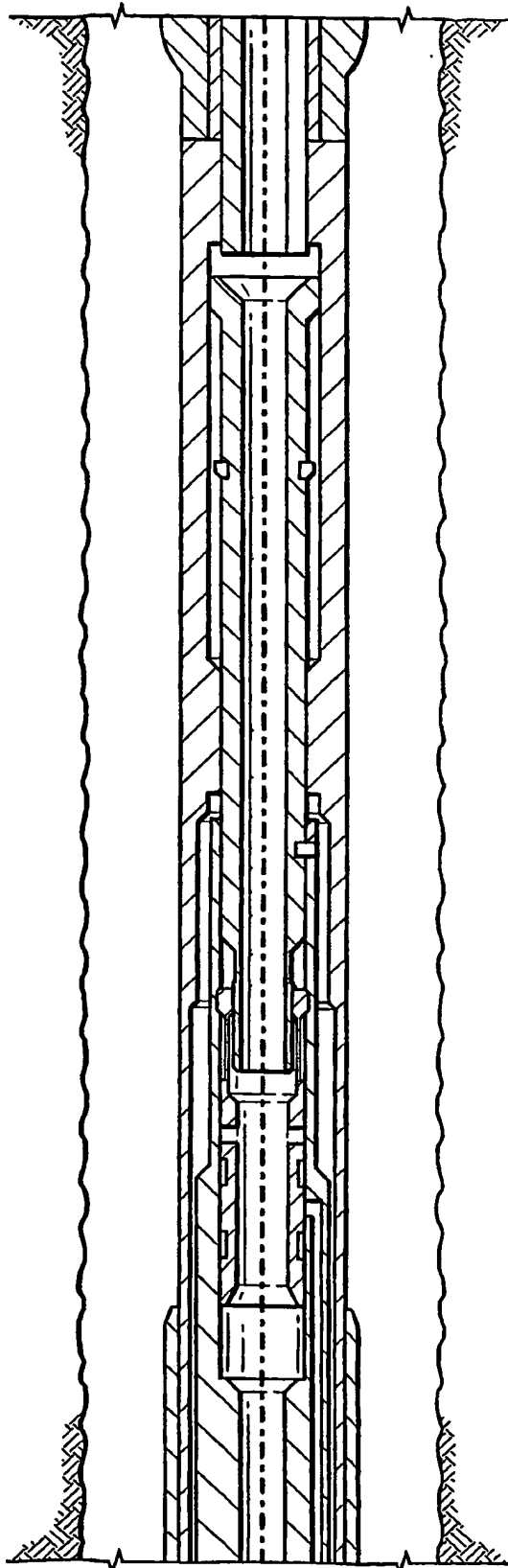


Fig. 3e

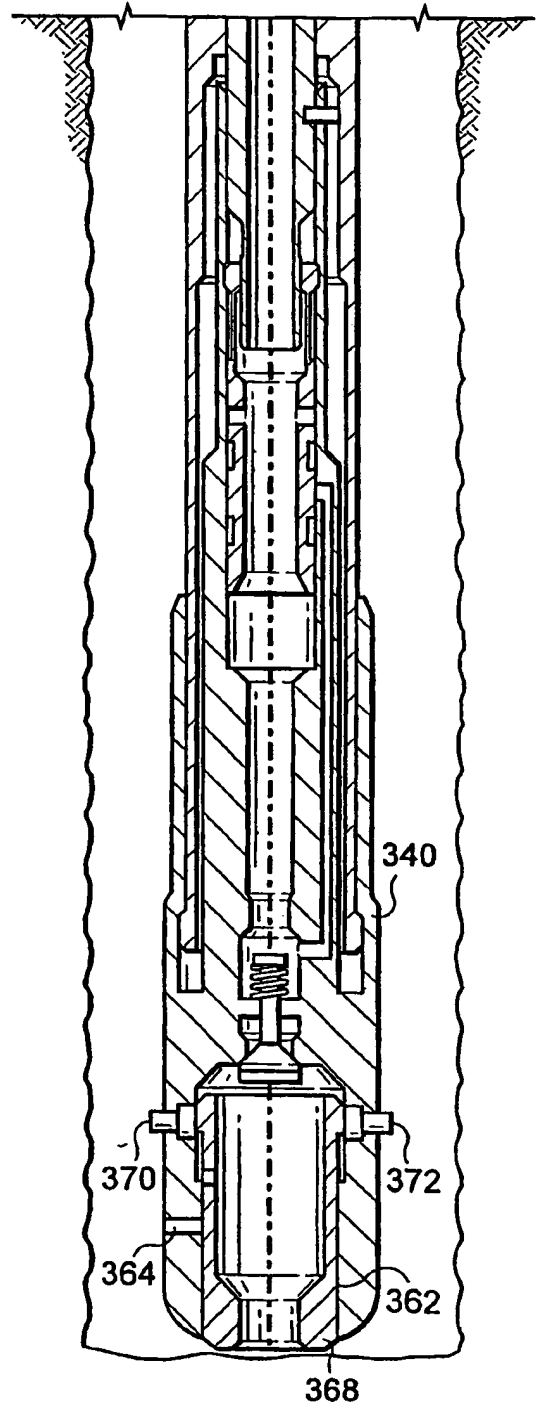


Fig. 3f

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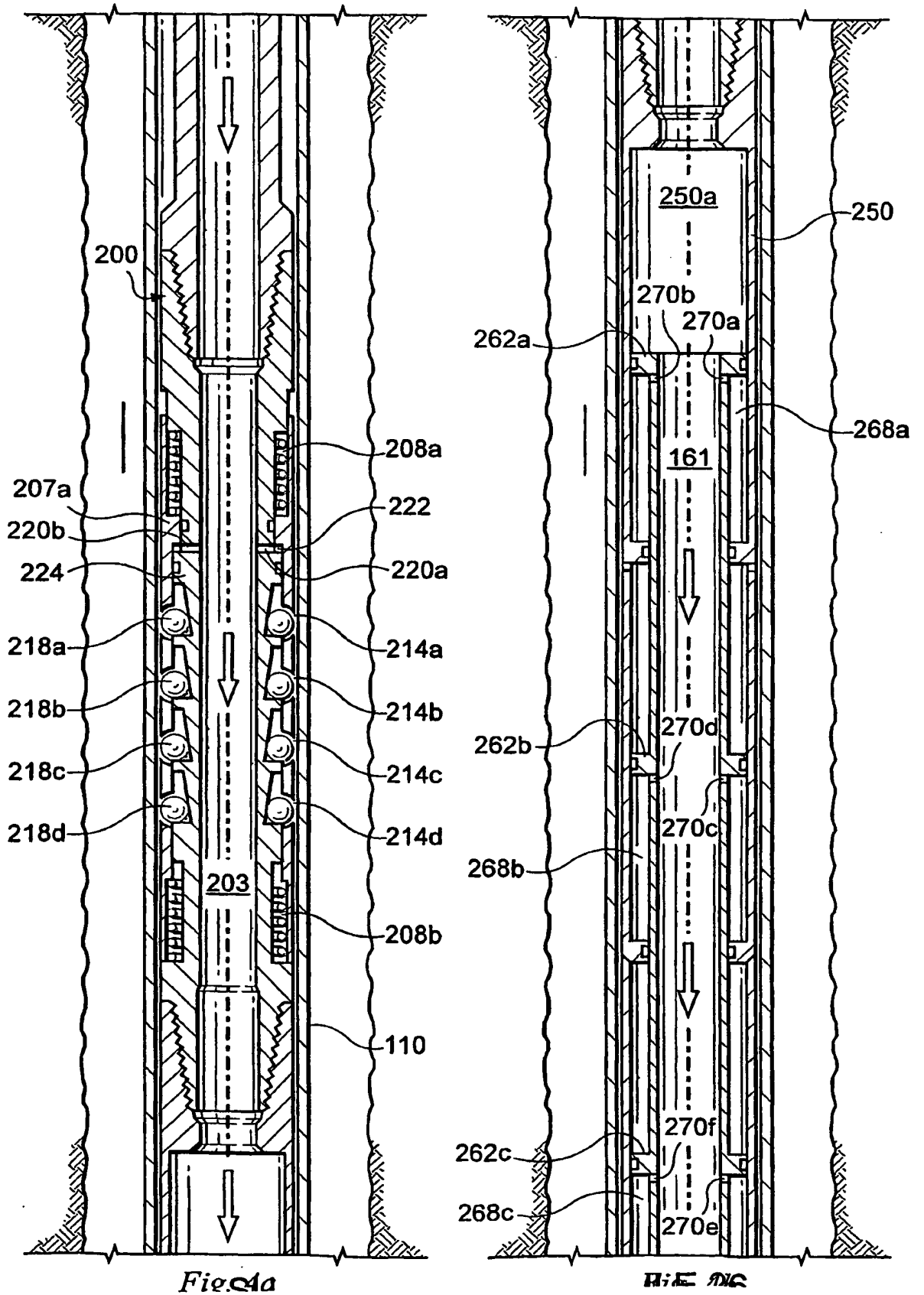


Fig. 4a

Fig. 4b

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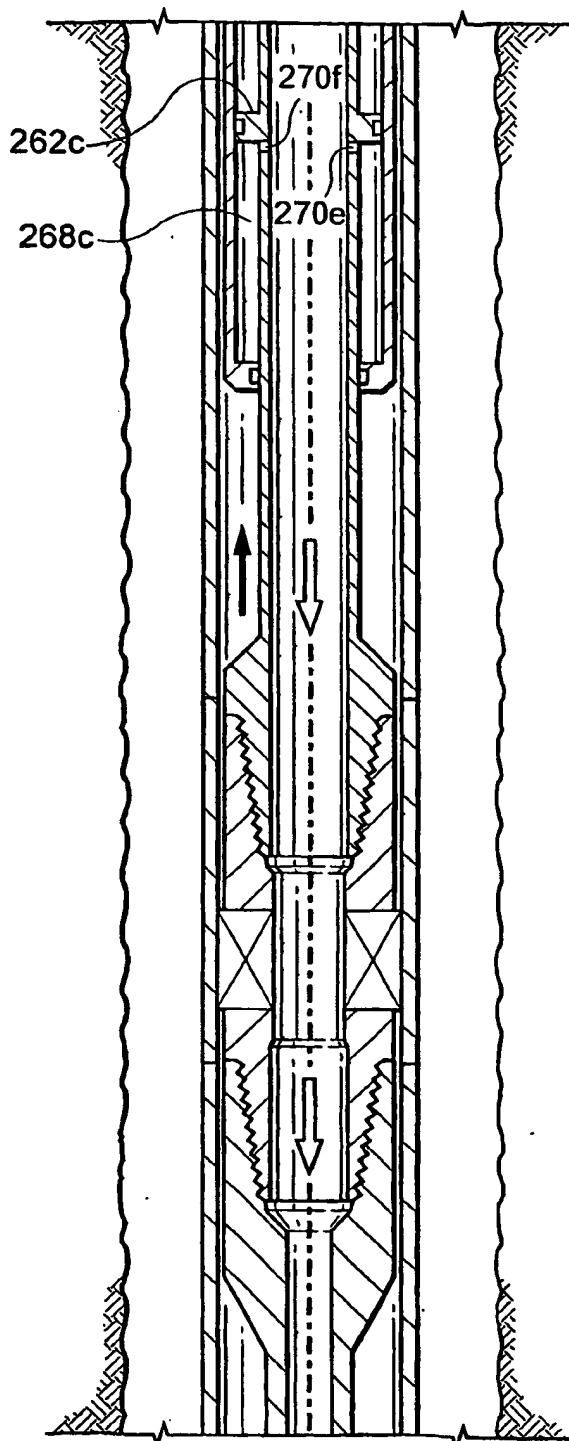


Fig. 4c

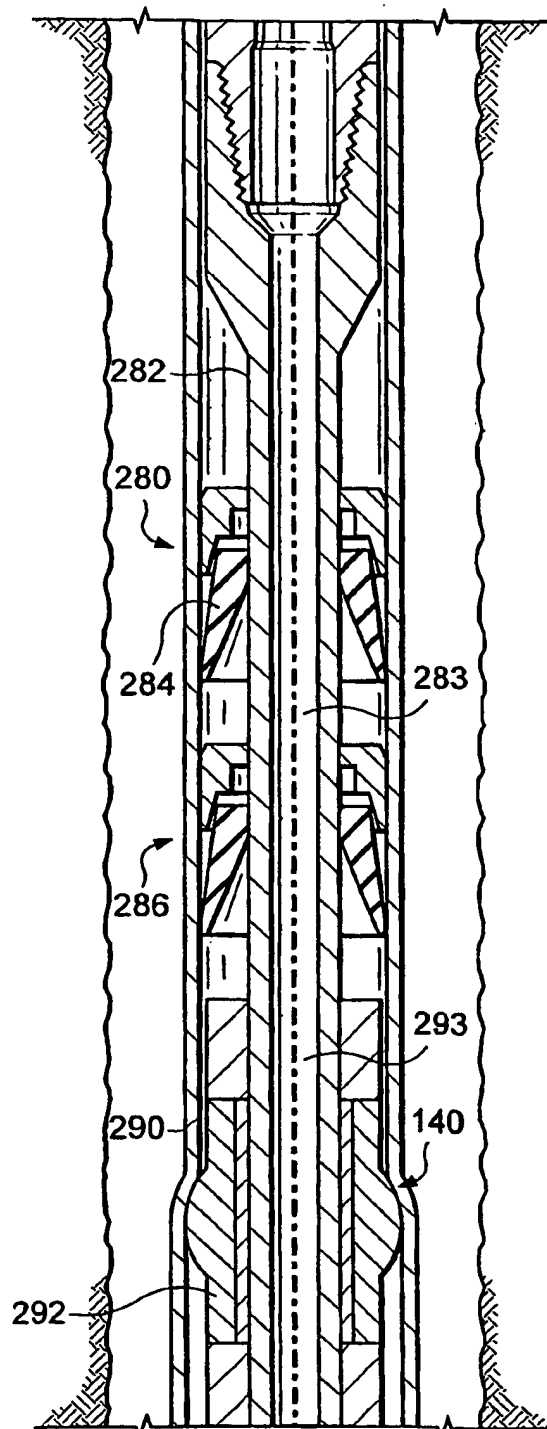


Fig 4d

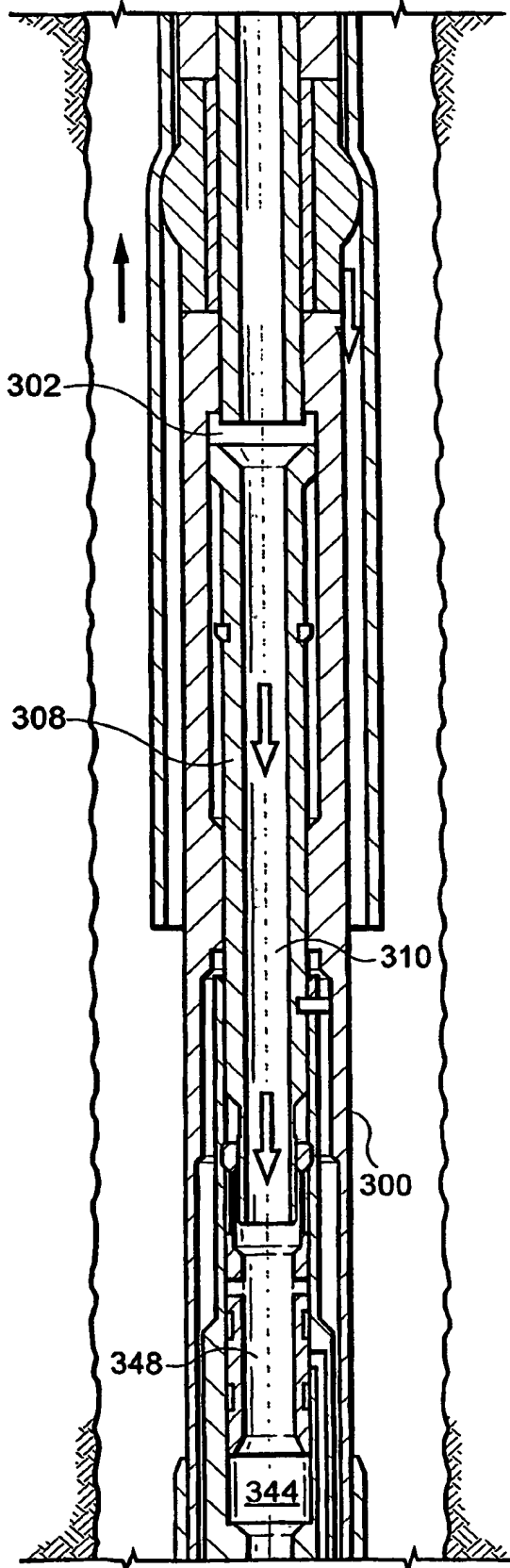


Fig 4A

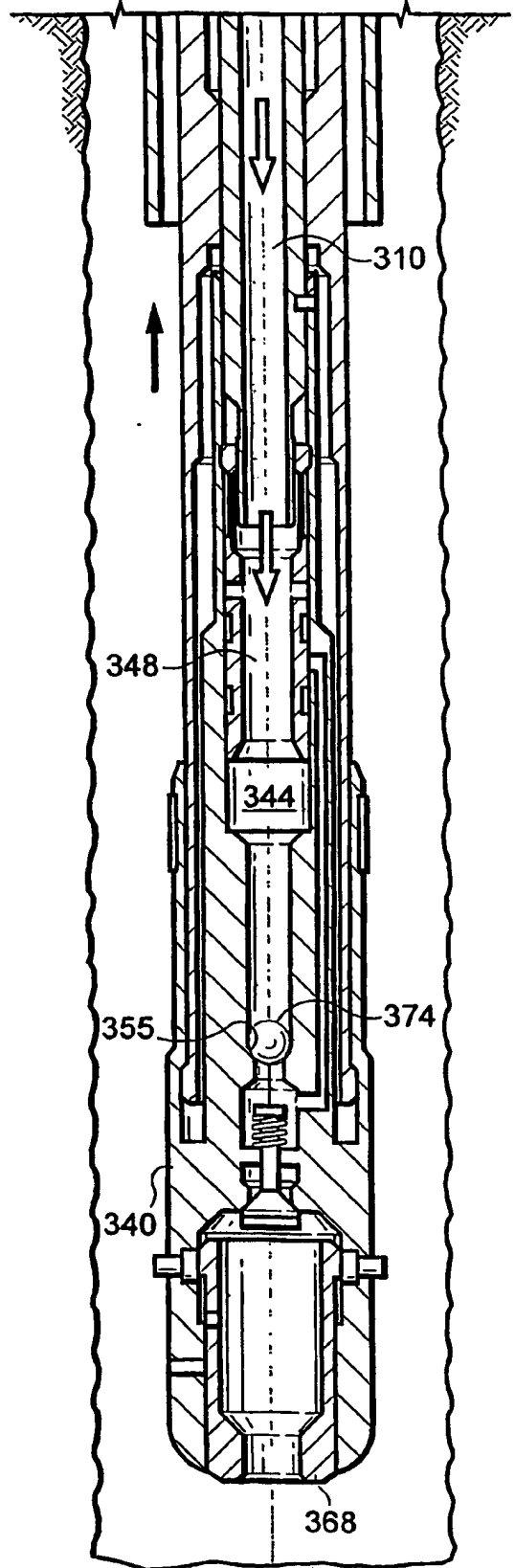


Fig 4B

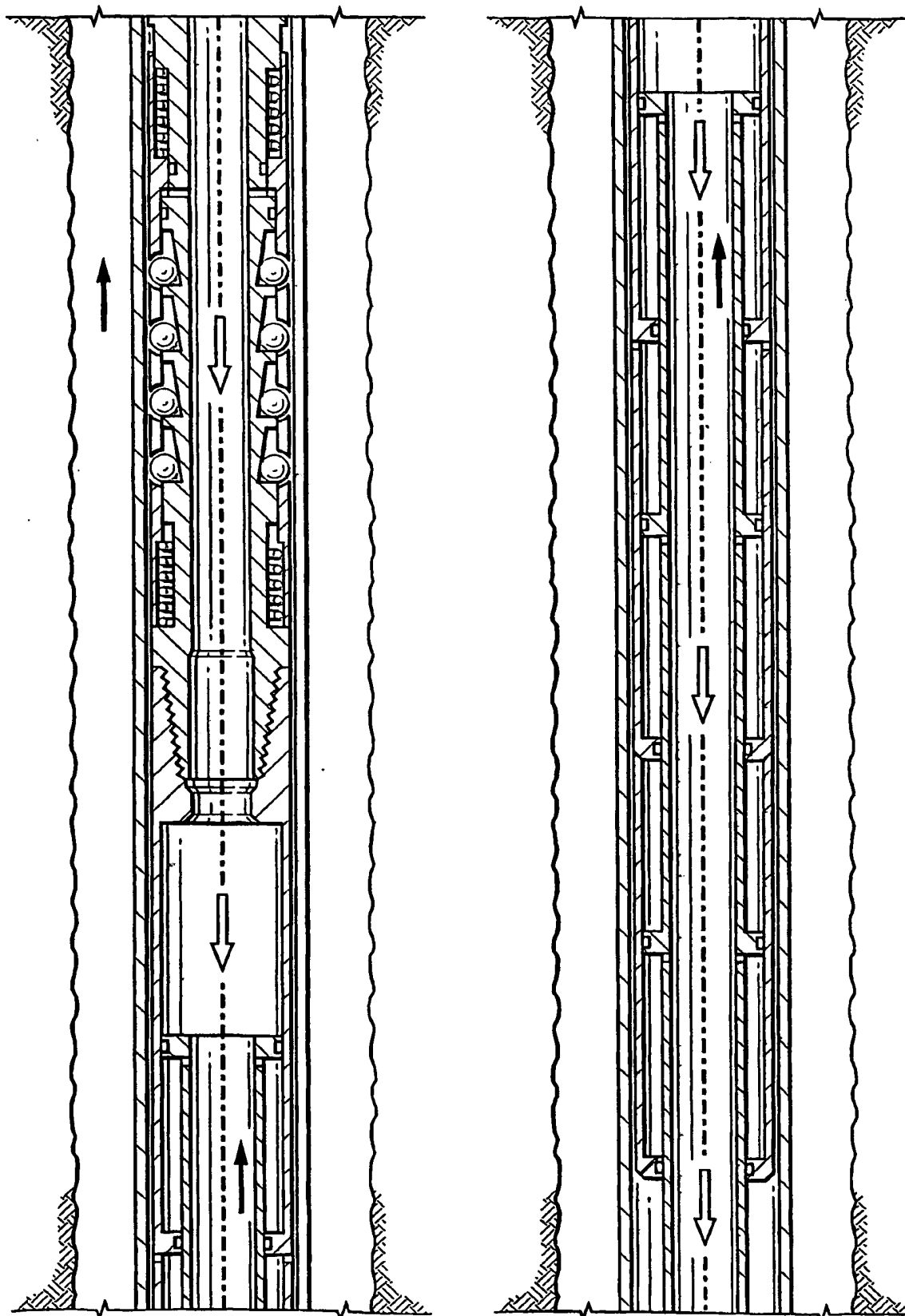


Fig. 9A

Fig. 9B

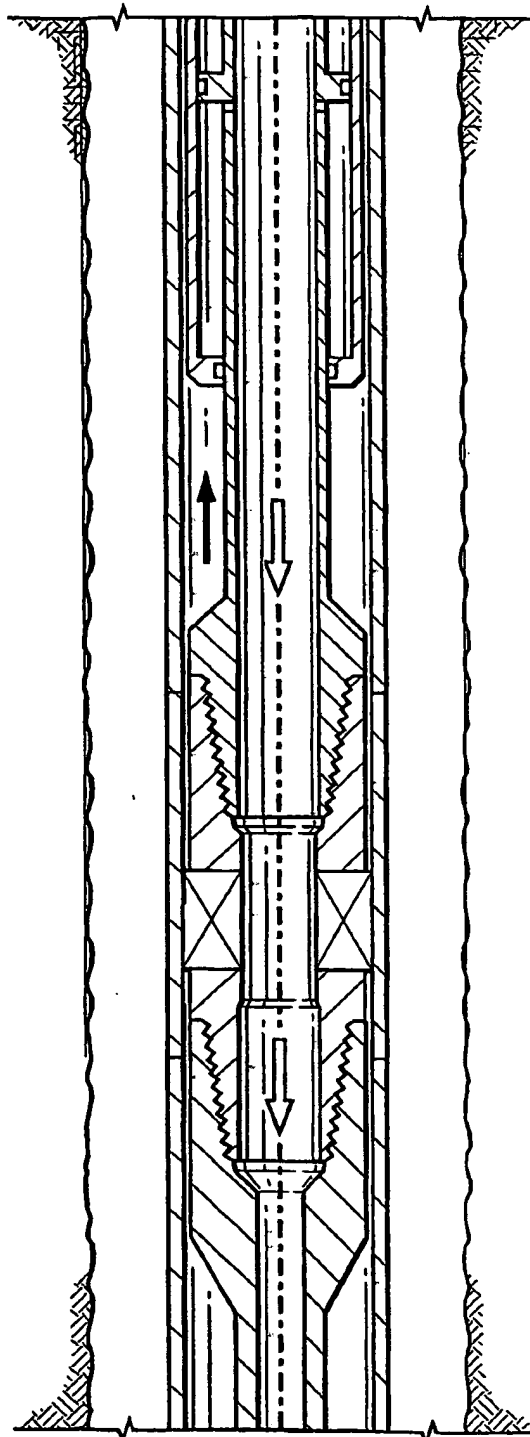


Fig. 5c

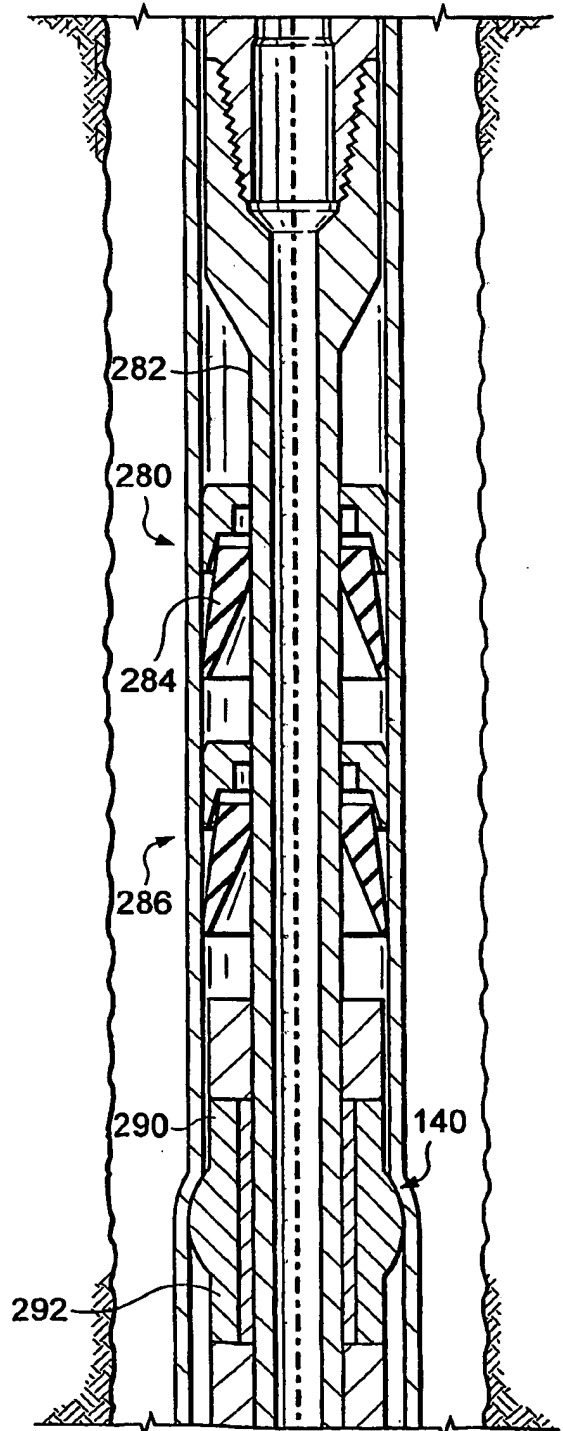


Fig. 5d

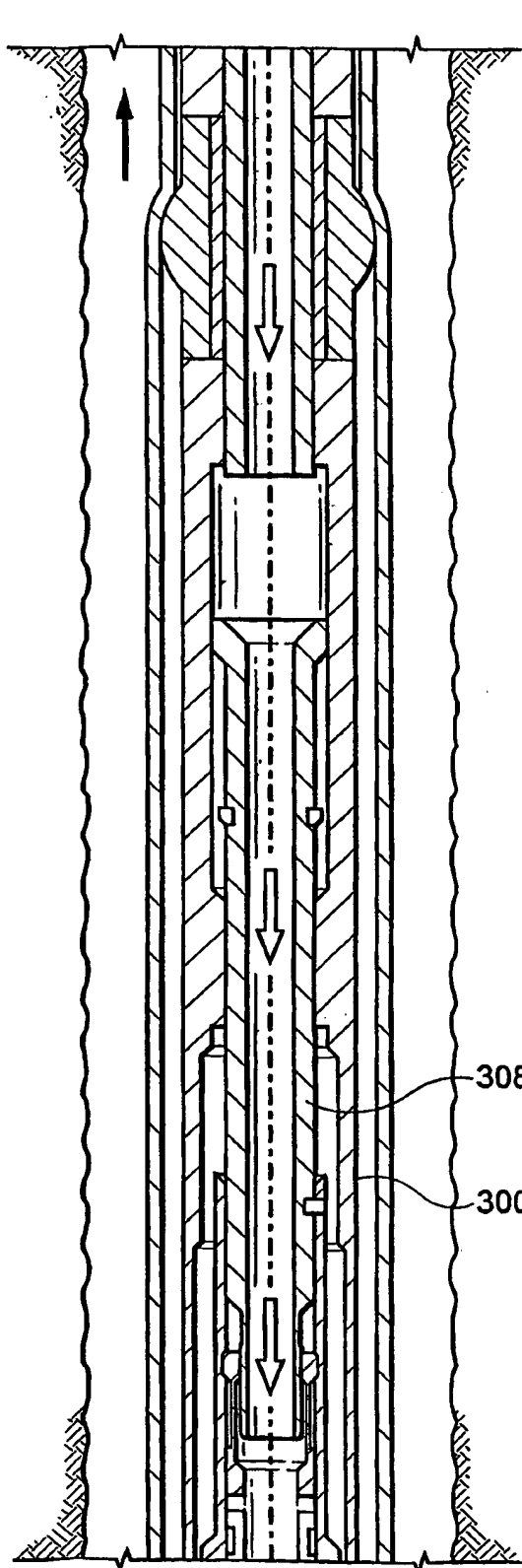


Fig. 5e

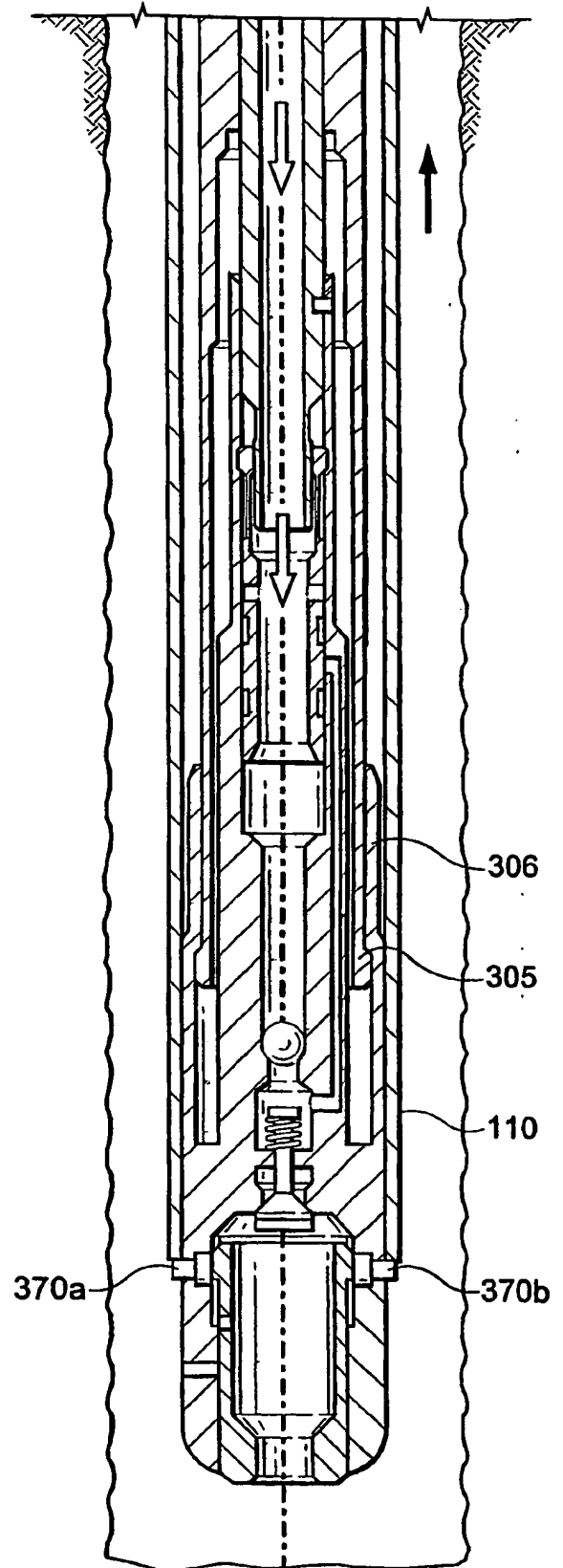


Fig. 5f

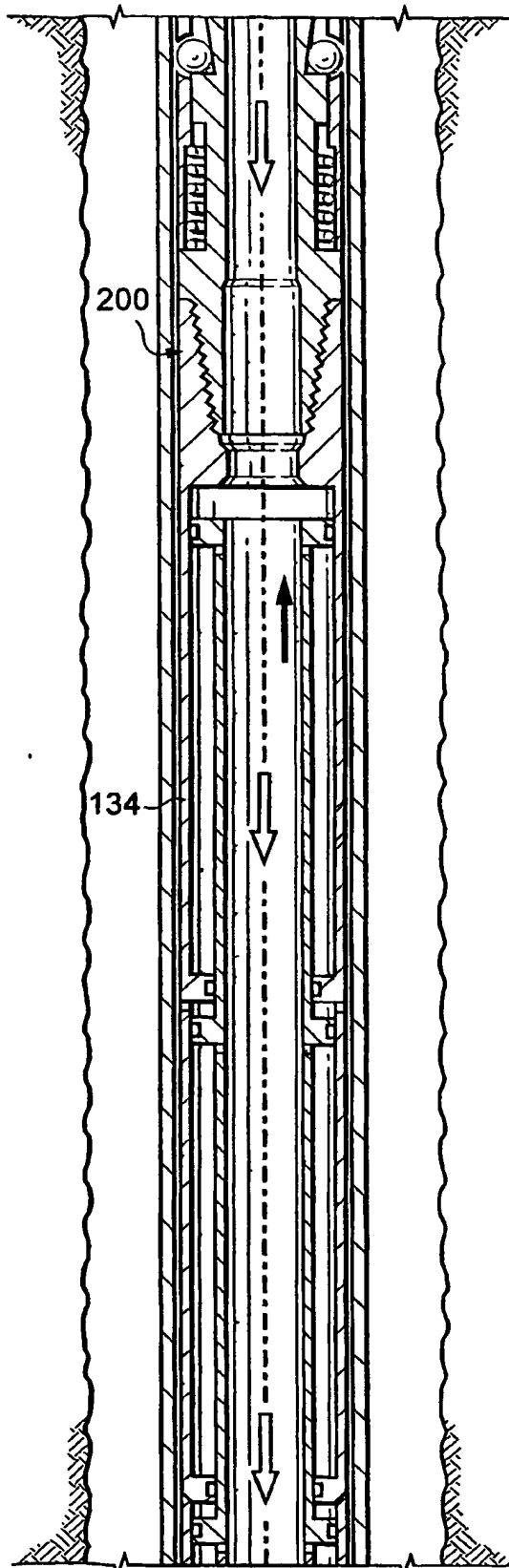


Fig. 6a

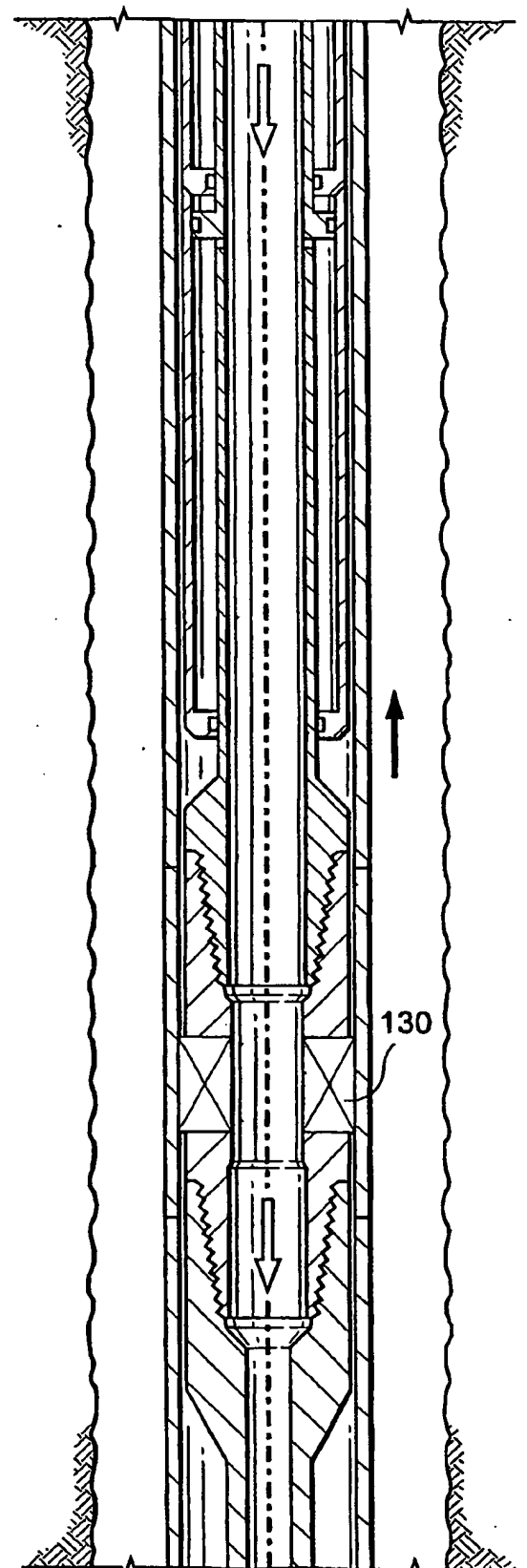


Fig. 6b

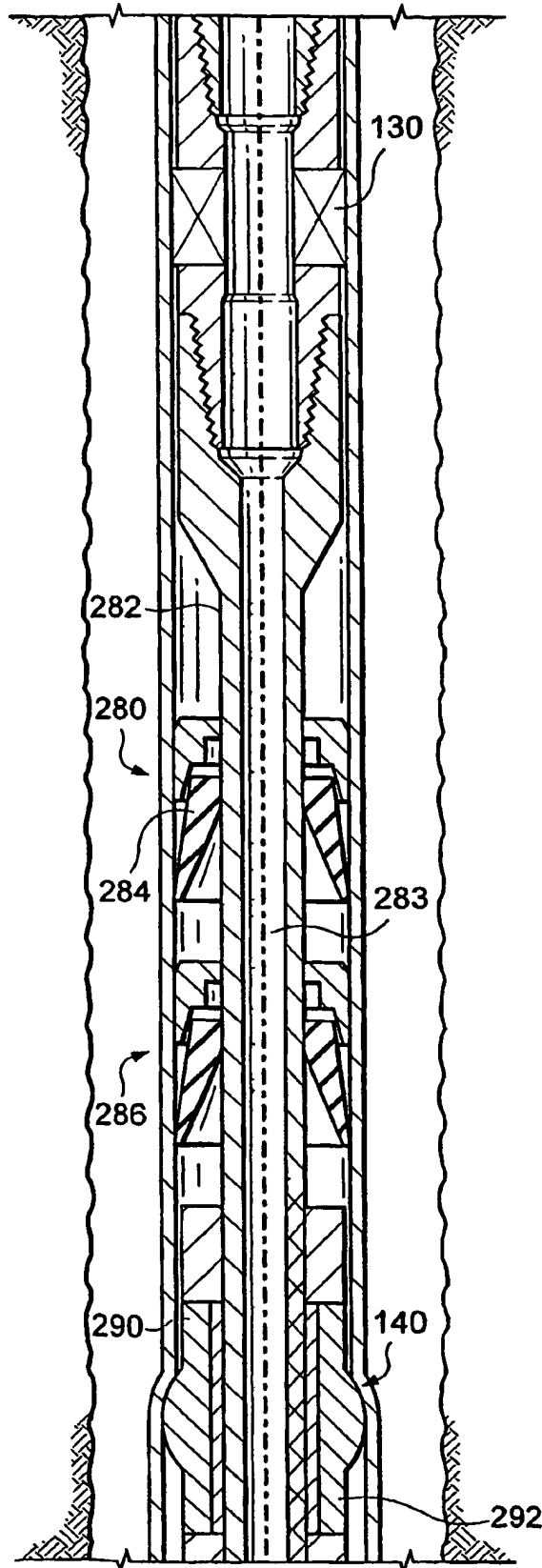


Fig. 6c

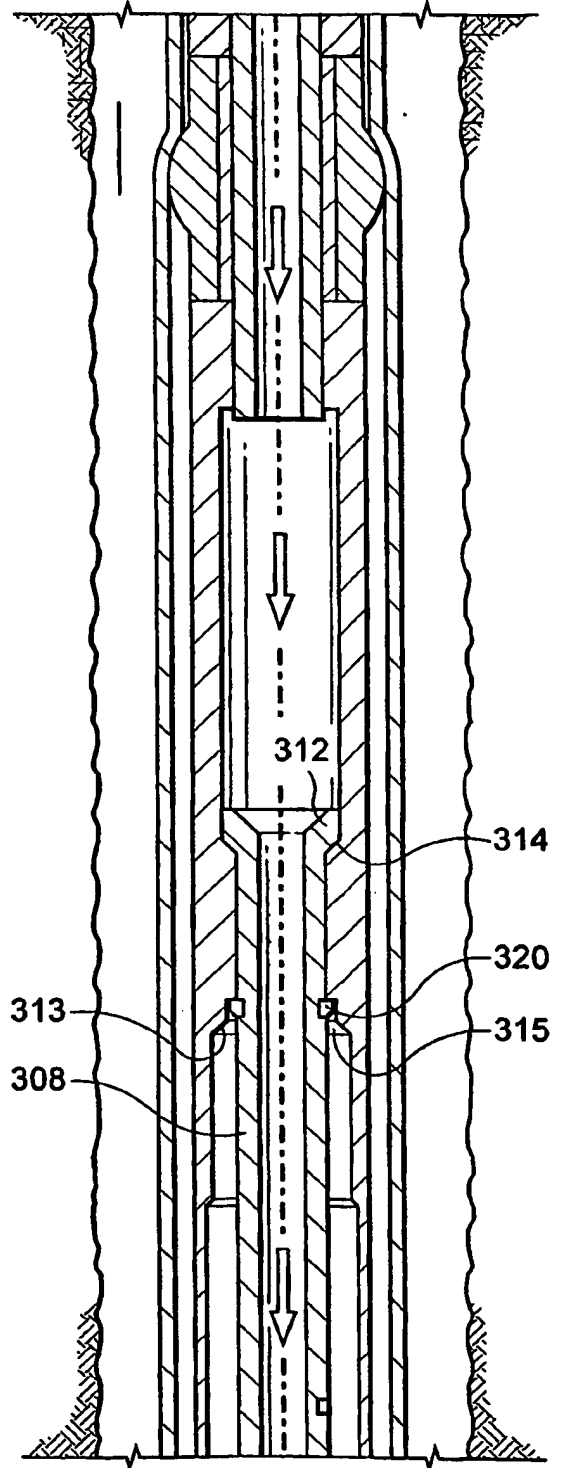


Fig. 6d

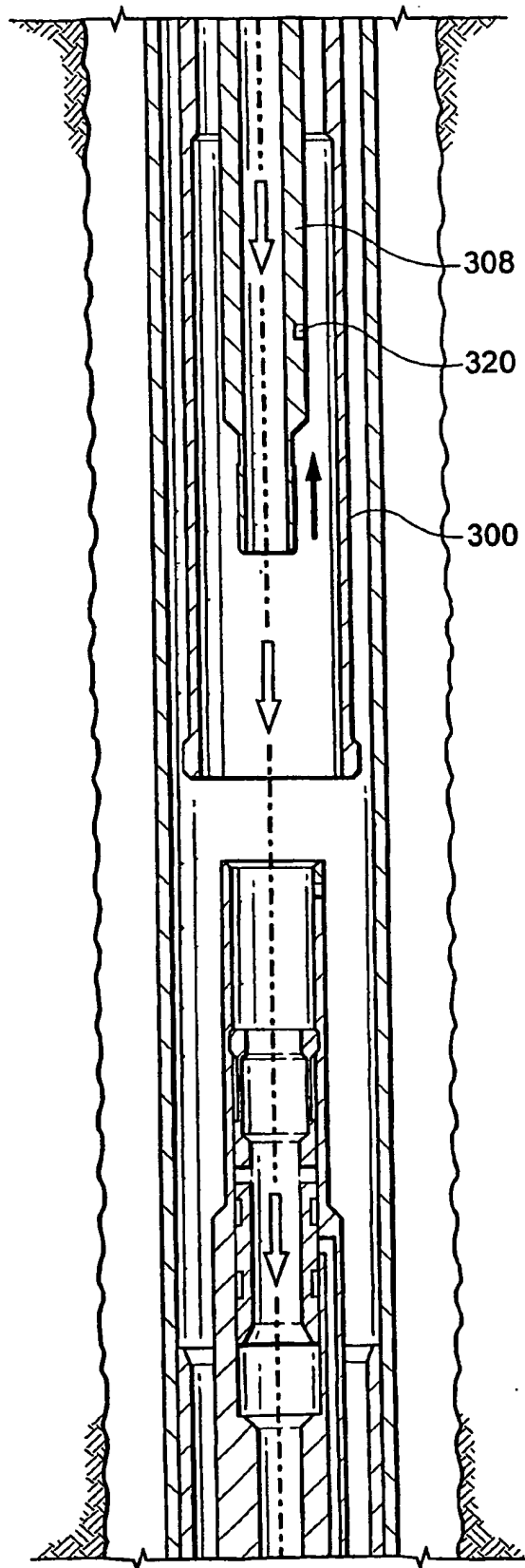


Fig. 6a

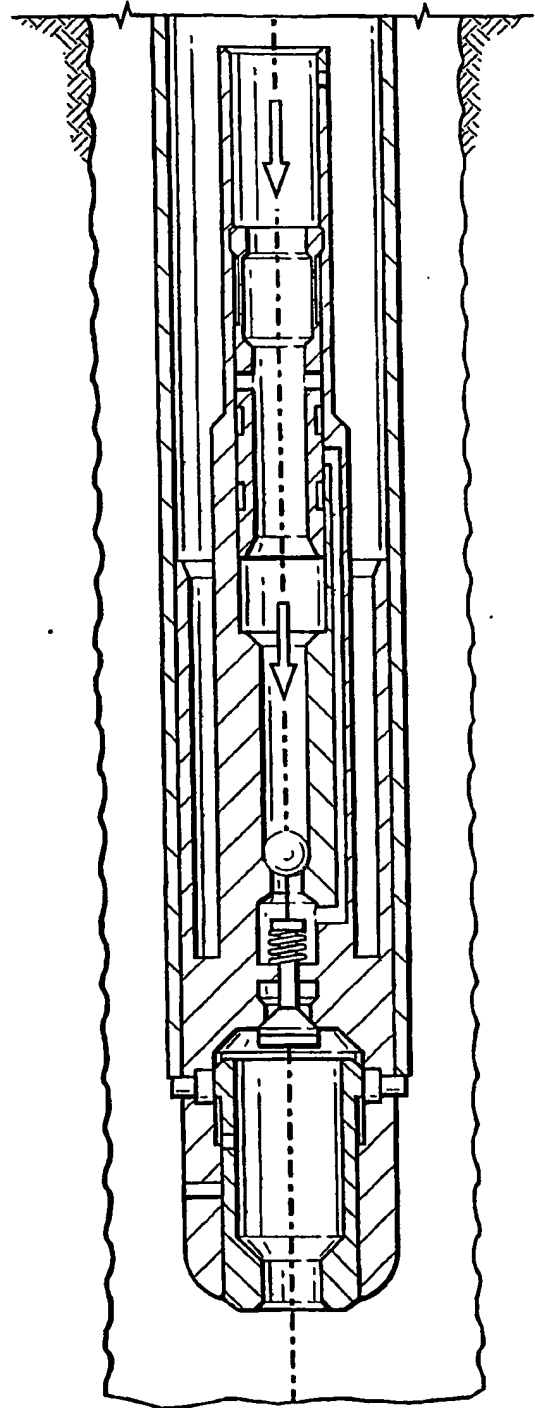


Fig. 6f

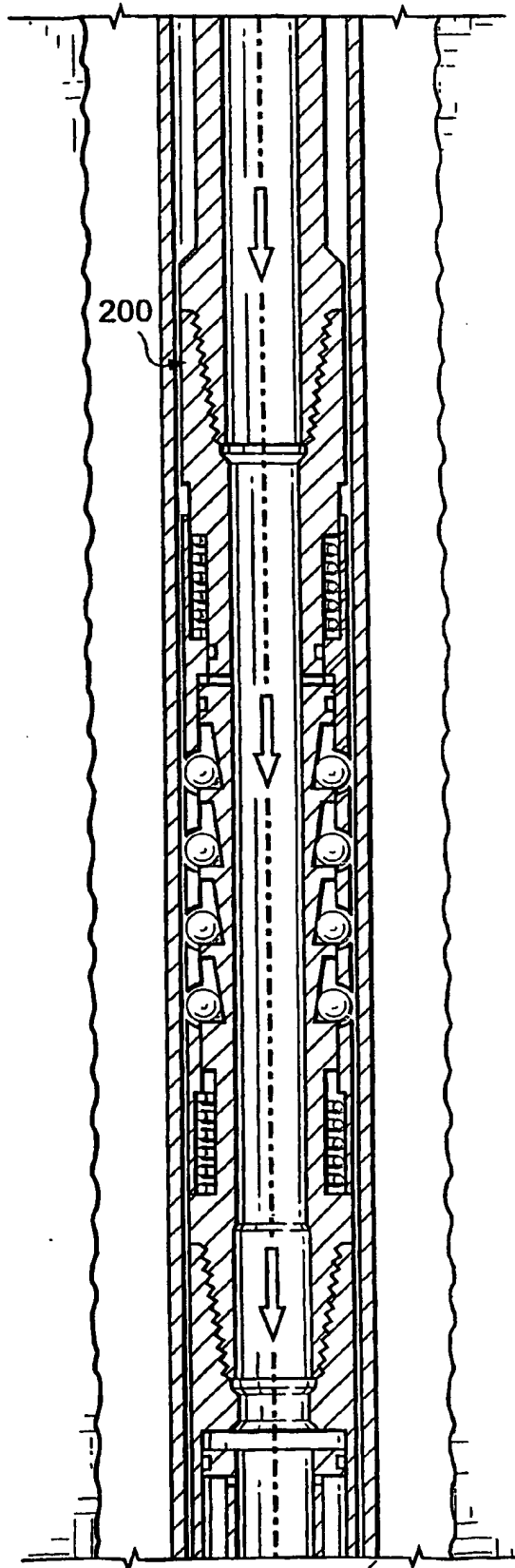


Fig. 7a

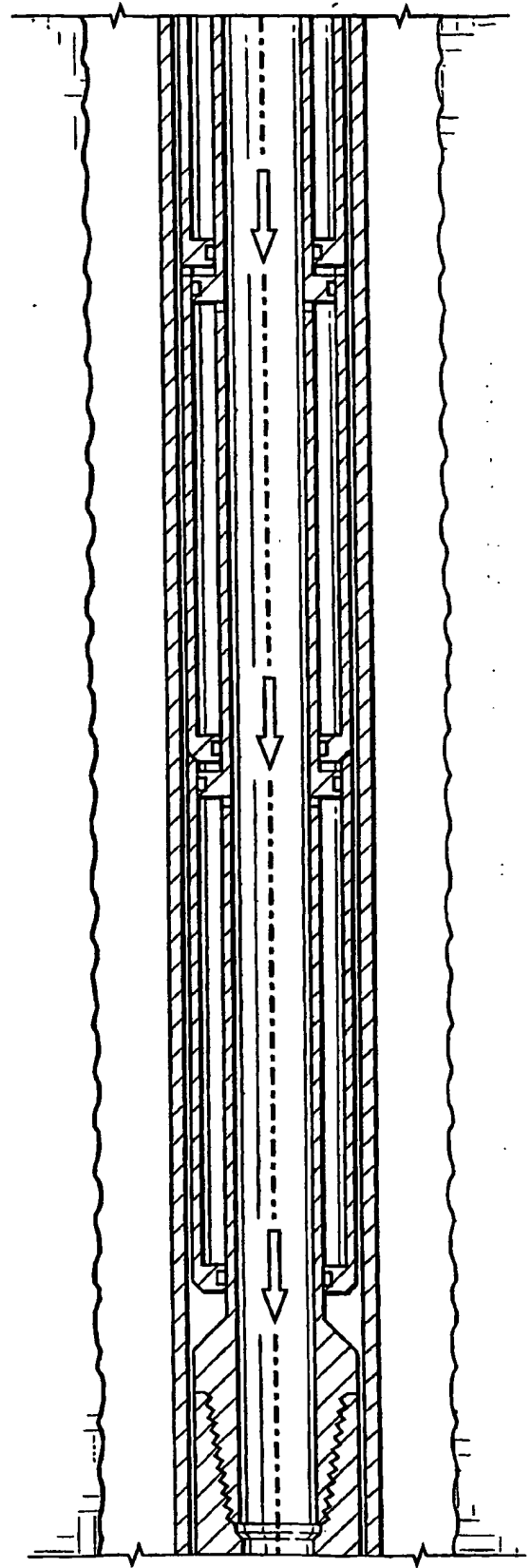


Fig. 7b

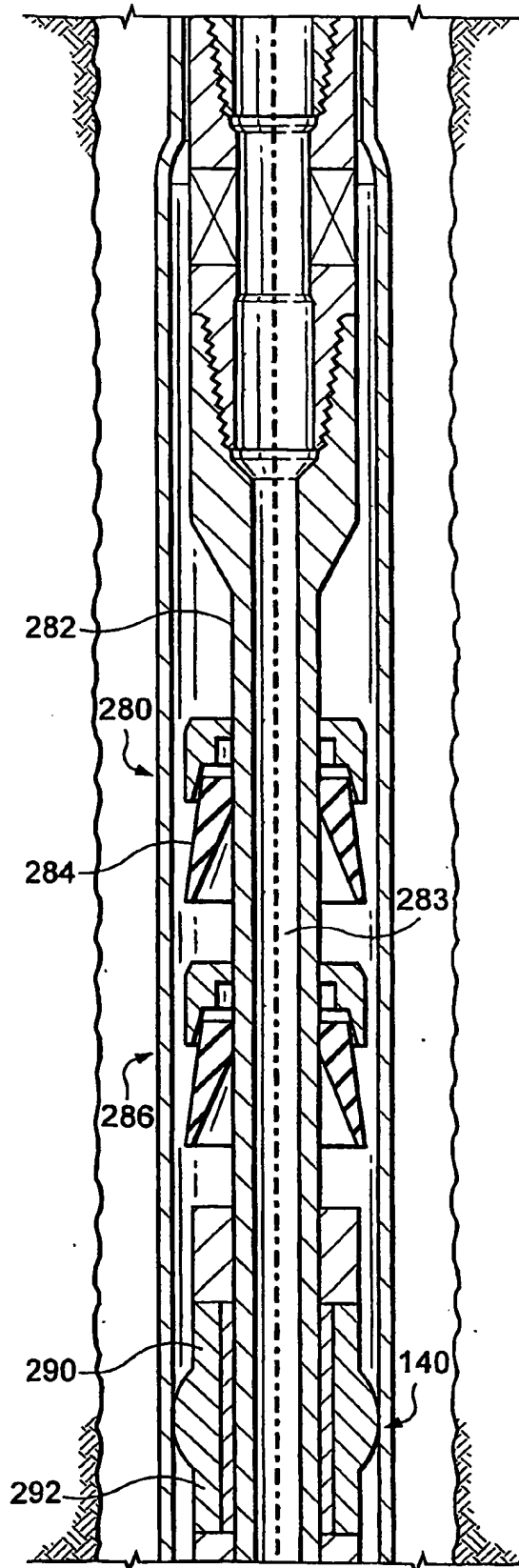


Fig. 7c

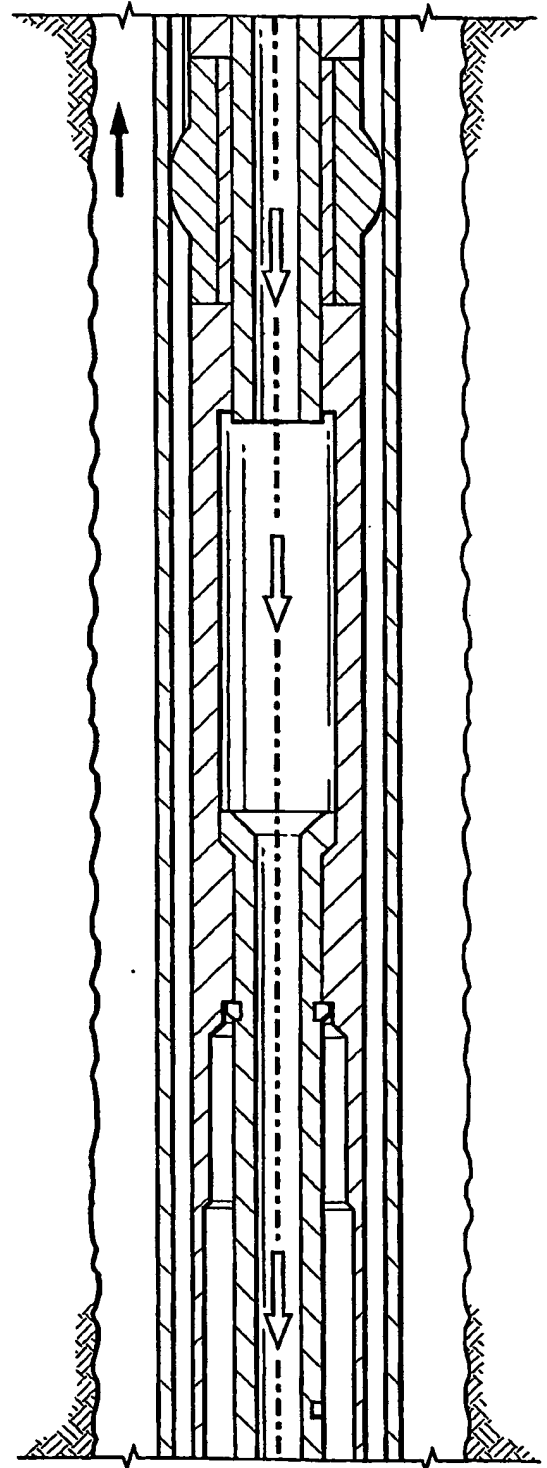


Fig. 7d

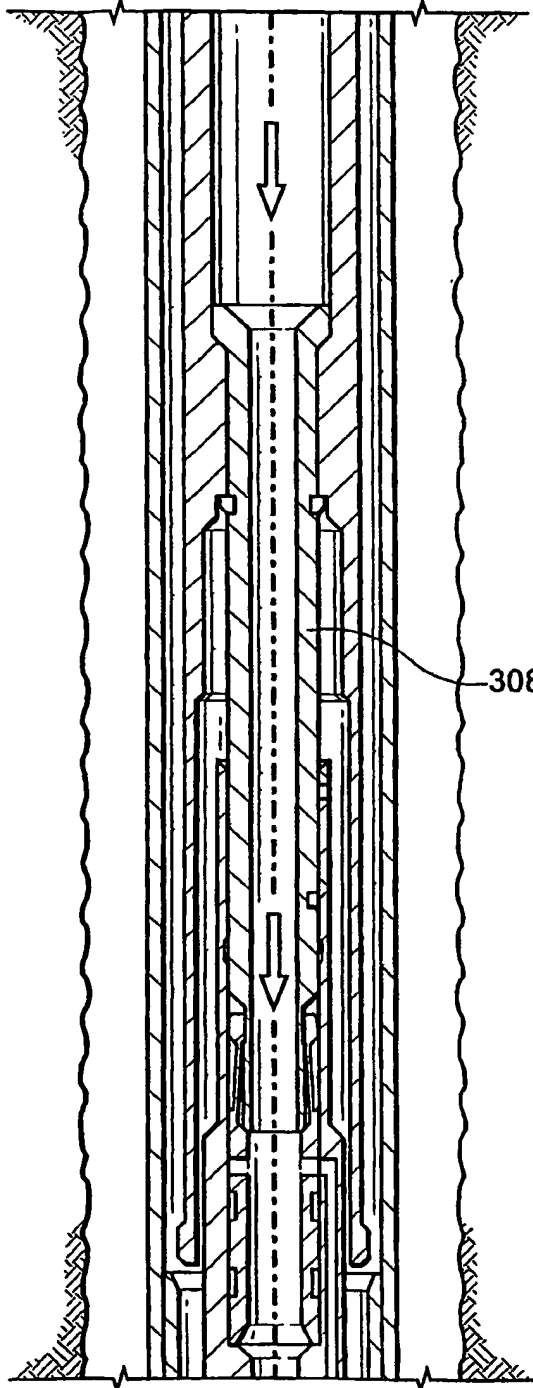


Fig. 7e

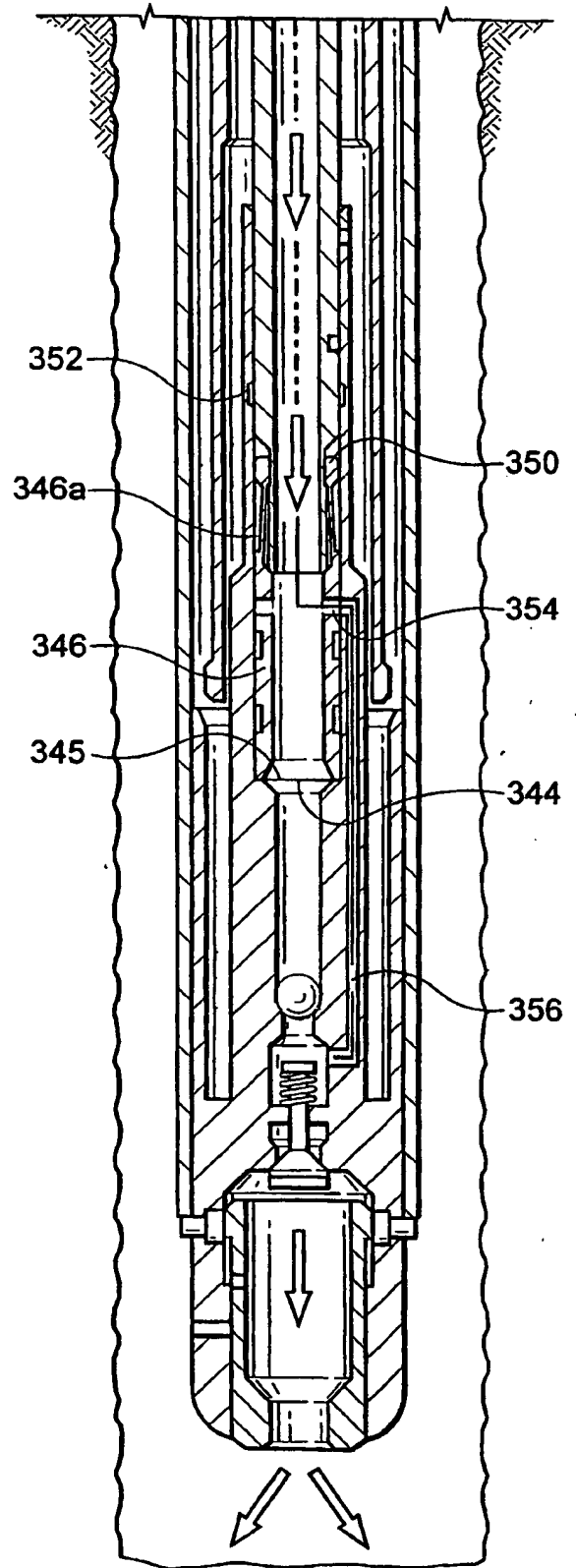


Fig. 7f

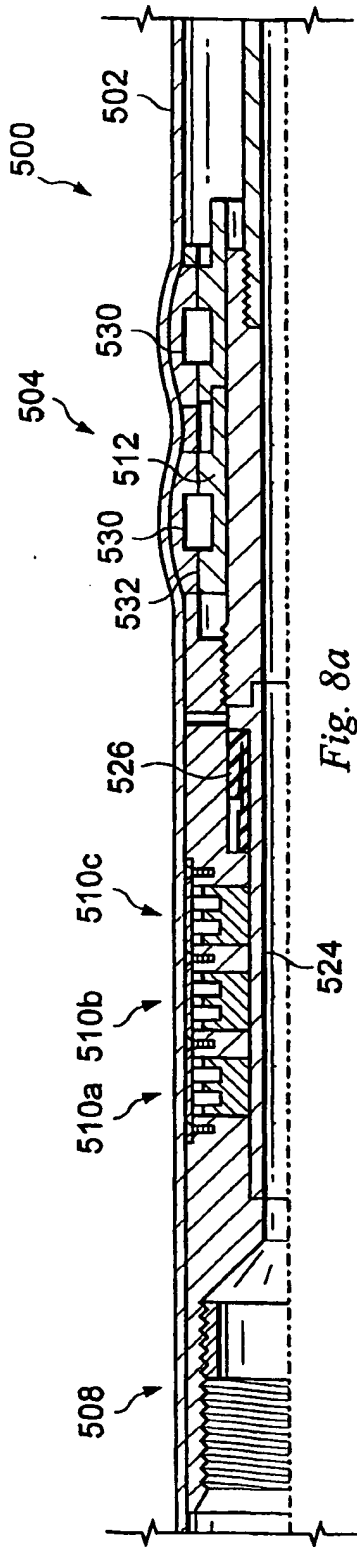


Fig. 8a

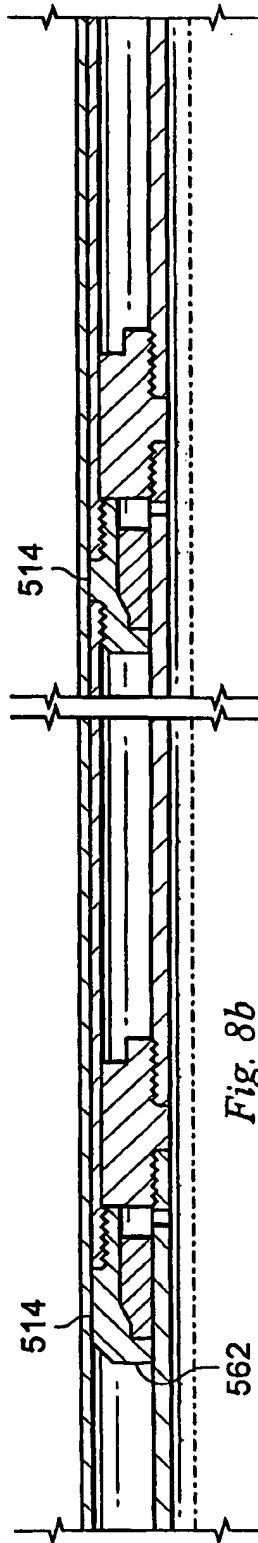


Fig. 8b

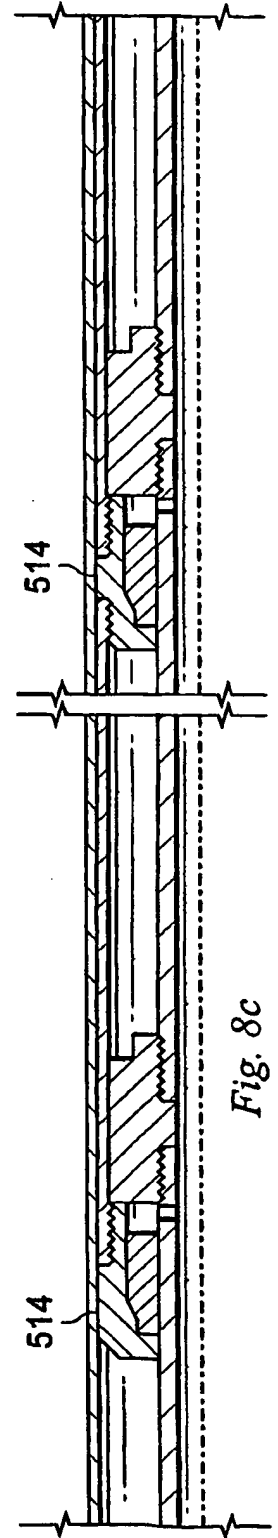


Fig. 8c

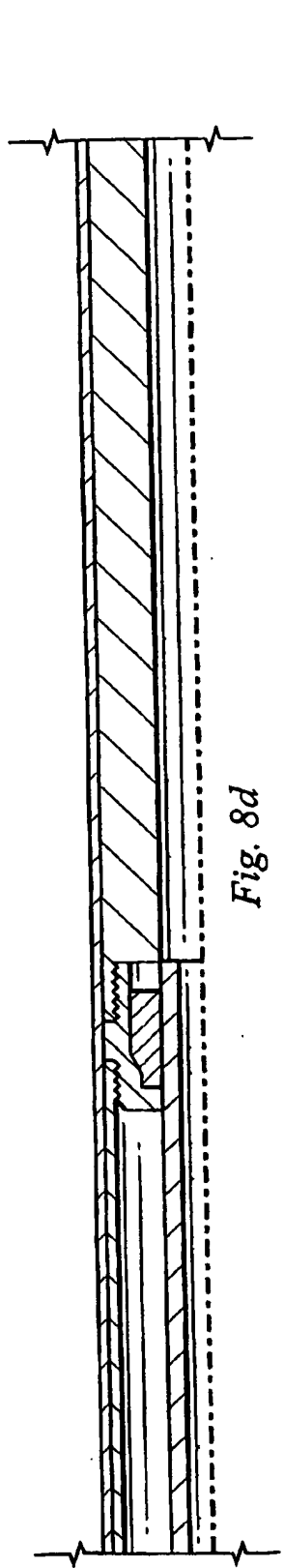


Fig. 8d

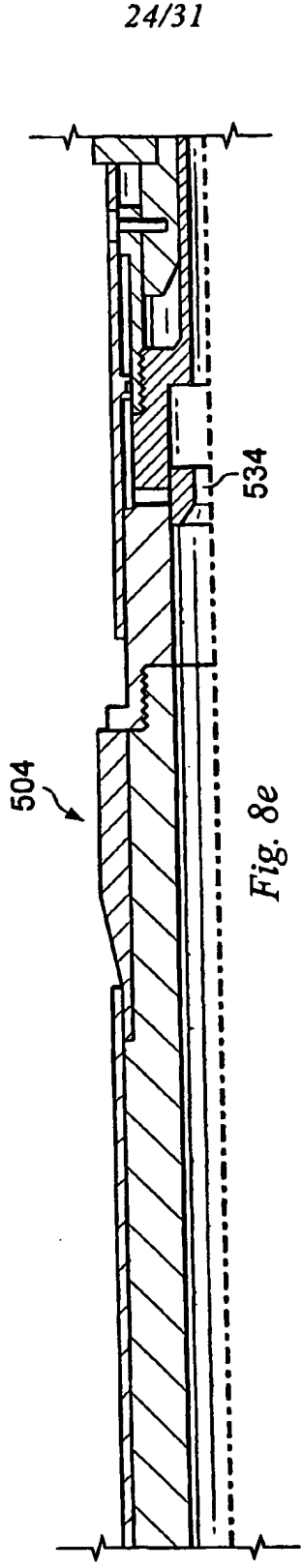


Fig. 8e

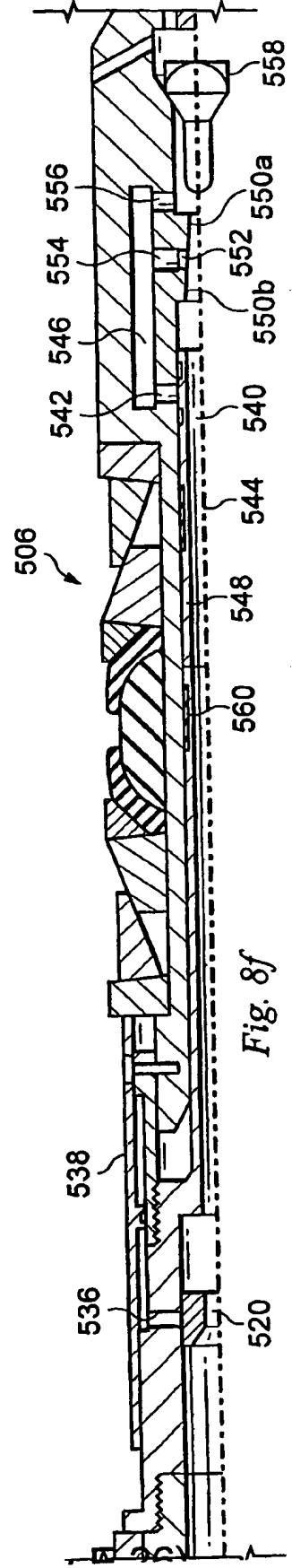


Fig. 8f

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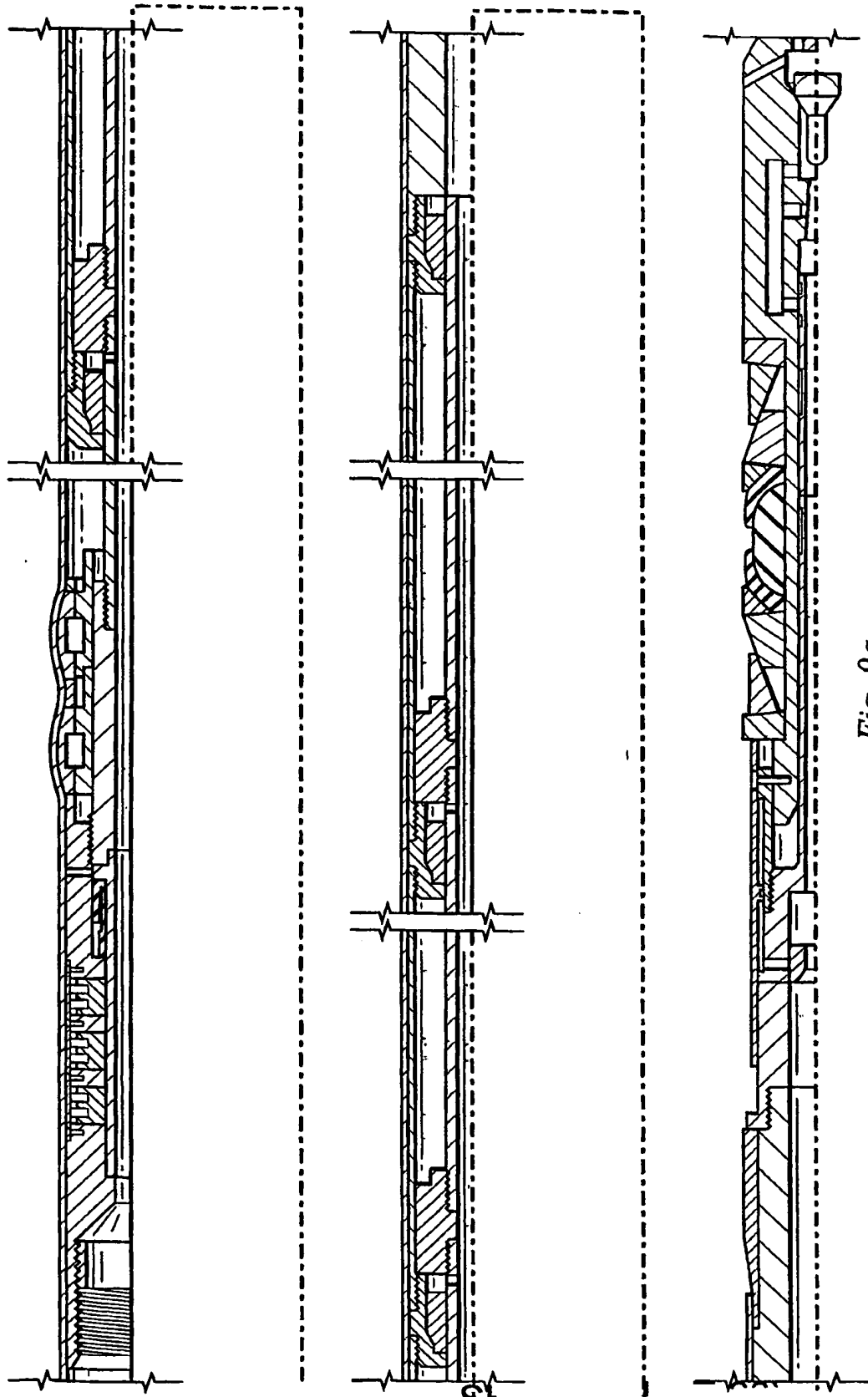


Fig. 9a

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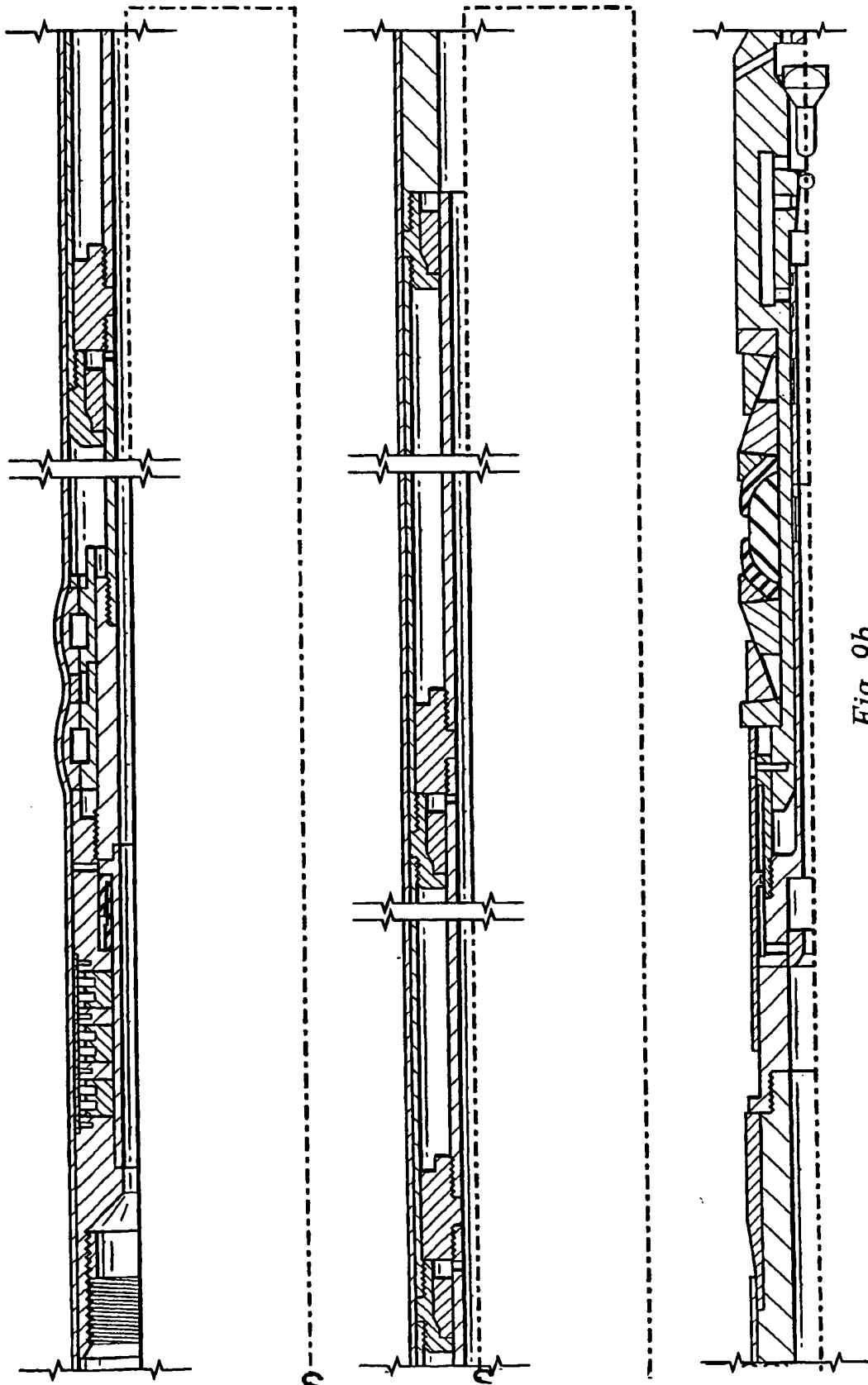


Fig. 9b

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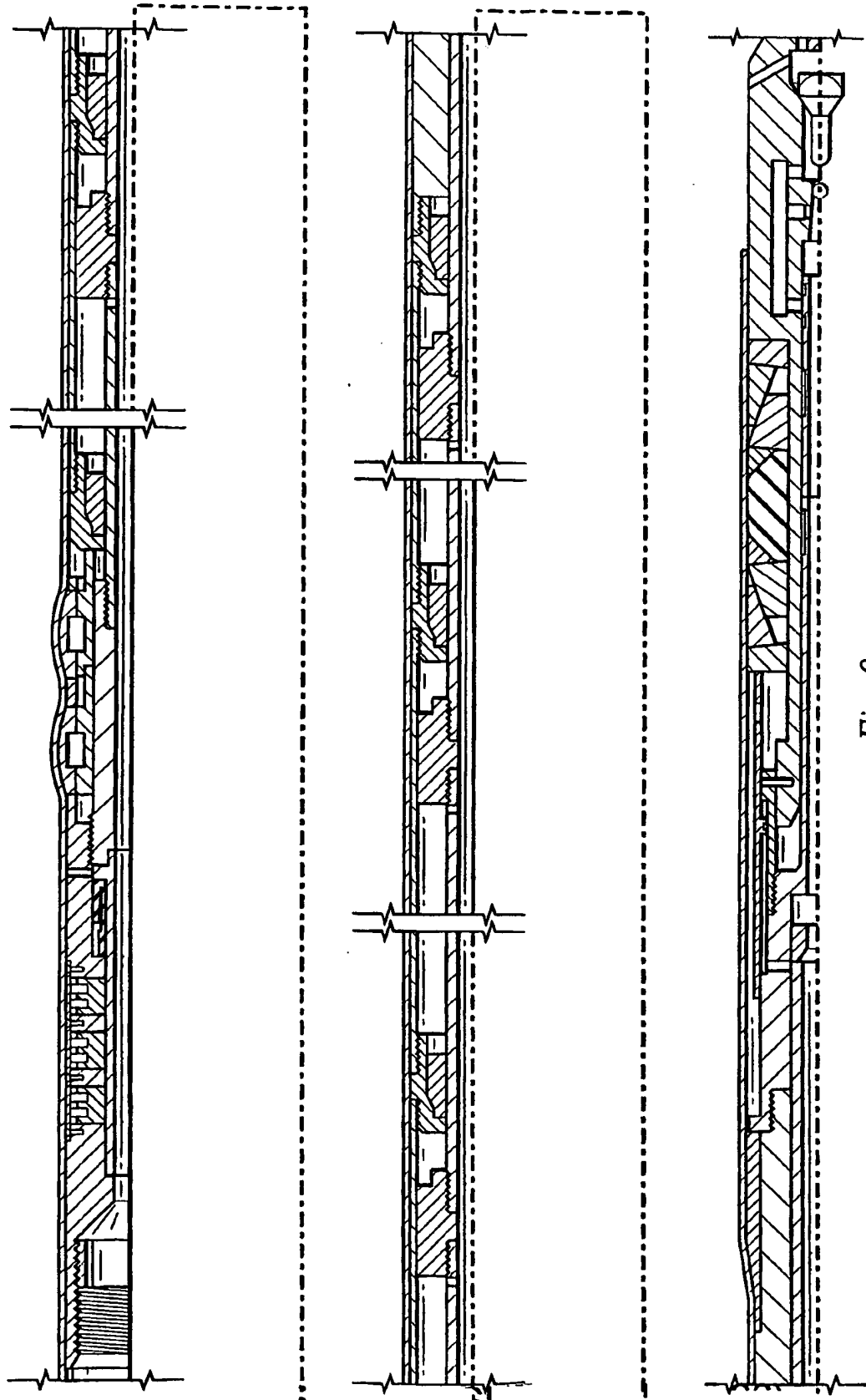


Fig. 9c

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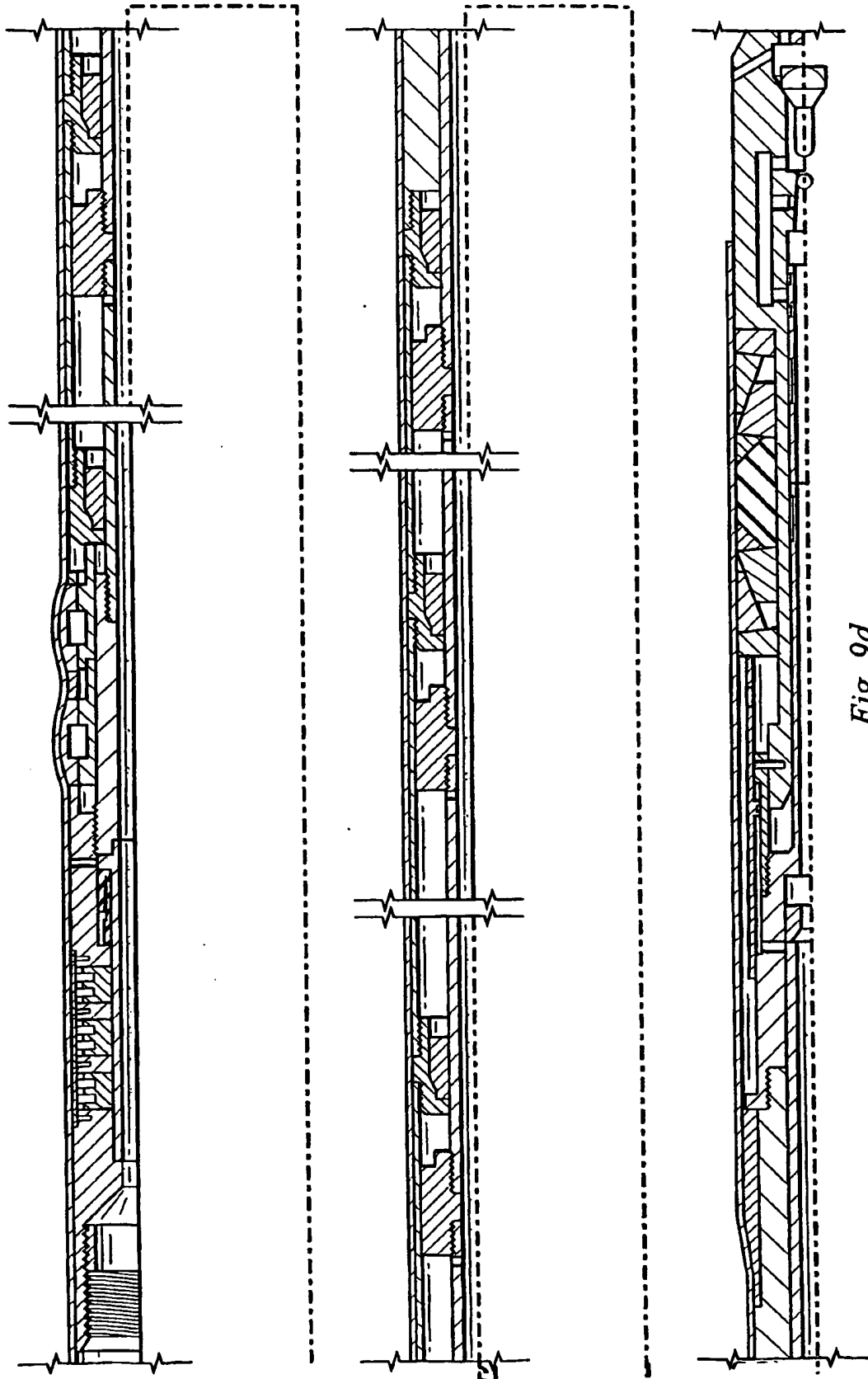


Fig. 9d

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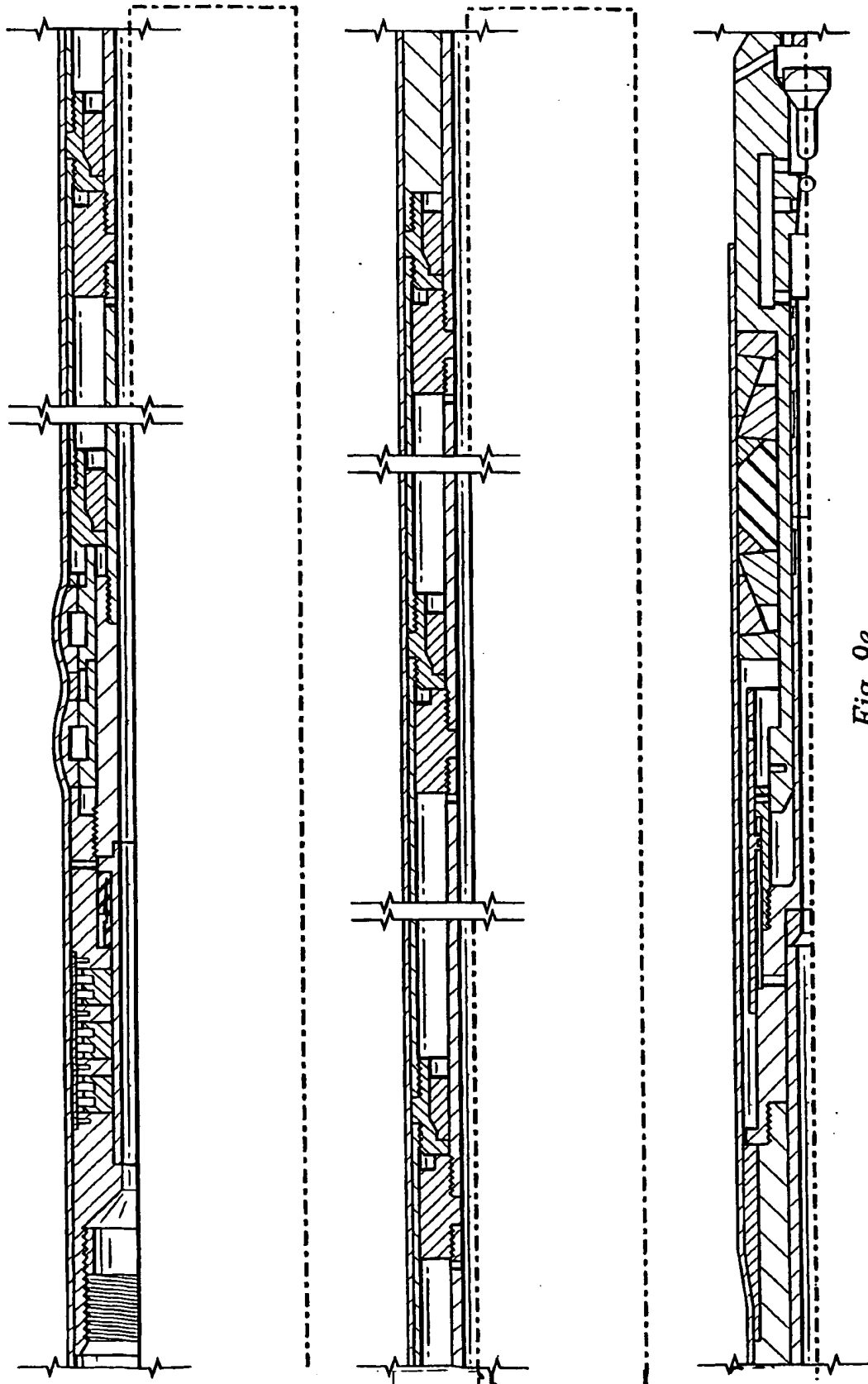


Fig. 9e

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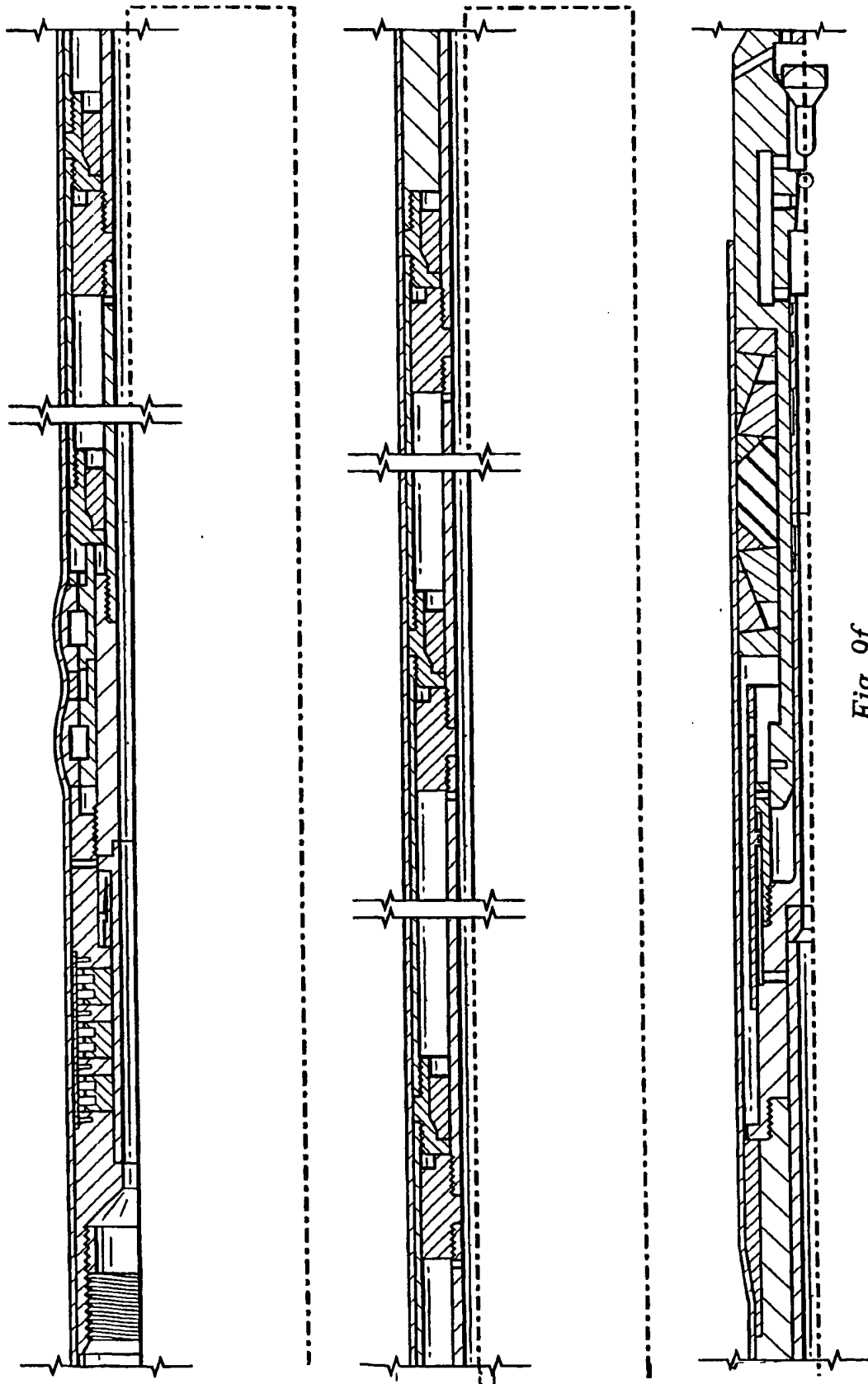


Fig. 9f

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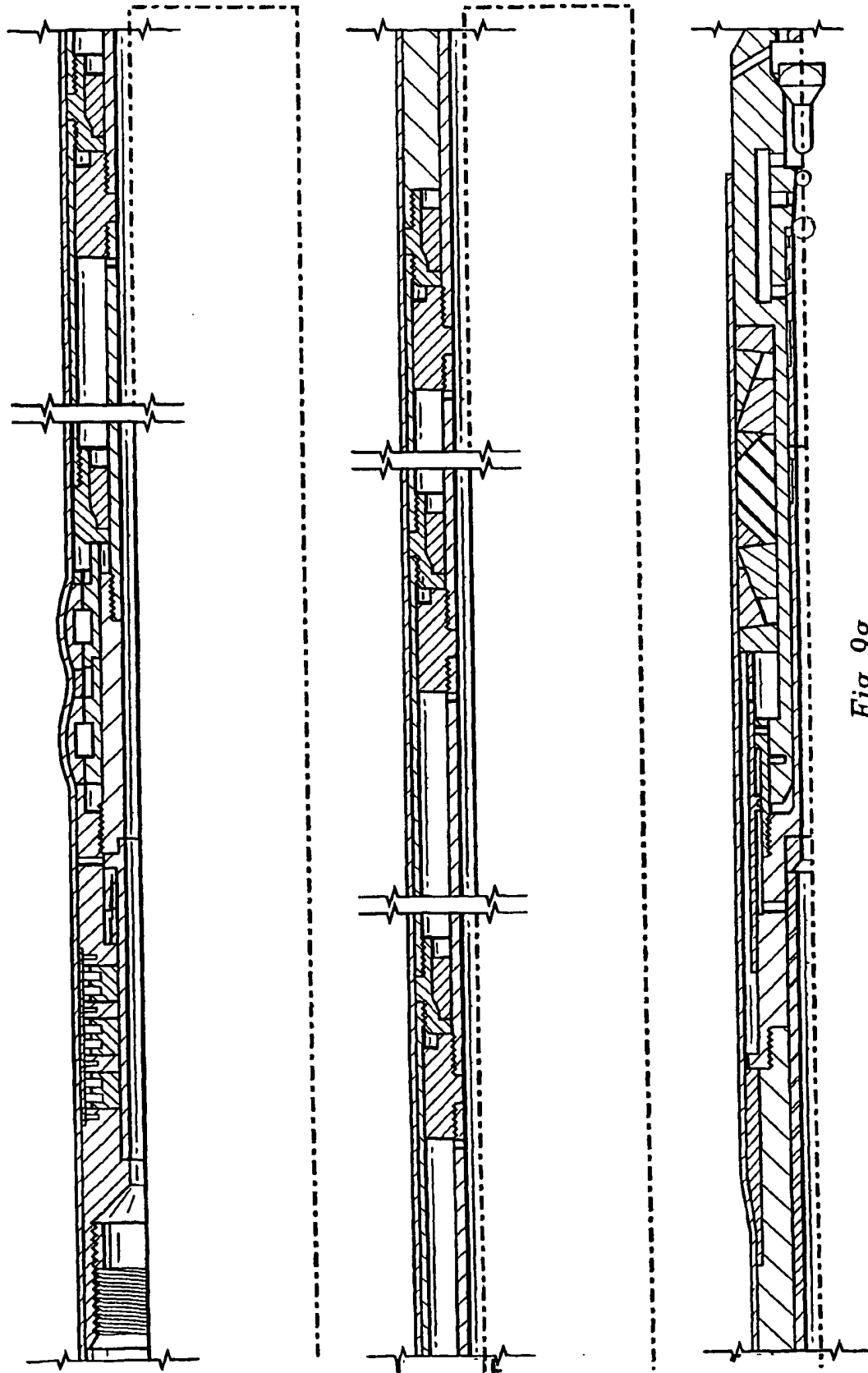


Fig. 98

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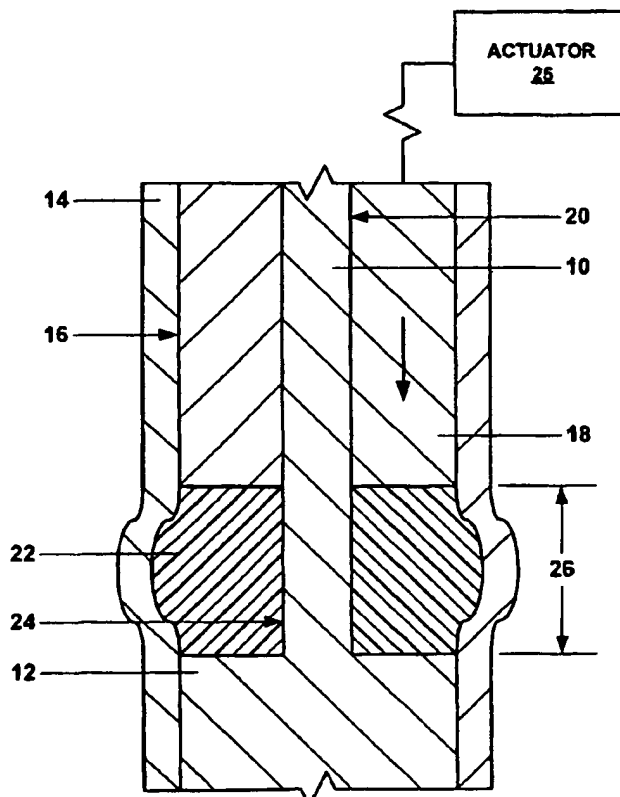
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[Continued on next page]

(54) Title: SYSTEM FOR RADIALLY EXPANDING A TUBULAR MEMBER



(57) Abstract: A system for radially expanding a tubular member (14).



WO 03/102365 A1



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Published:

- *with international search report*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

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SYSTEM FOR RADIALY EXPANDING A TUBULAR MEMBER**Cross Reference To Related Applications**

[001] The present application claims the benefit of the filing dates of (1) U.S. provisional patent application serial no. 60/383,917, attorney docket no 25791.89, filed on 5/29/2002, the disclosure of which is incorporated herein by reference.

[002] The present application is related to the following: (1) U.S. patent application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, (4) U.S. patent application serial no. 09/440,338, attorney docket no. 25791.9.02, filed on 11/15/1999, (5) U.S. patent application serial no. 09/523,460, attorney docket no. 25791.11.02, filed on 3/10/2000, (6) U.S. patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, (7) U.S. patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, (8) U.S. patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, (9) U.S. patent application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, (10) PCT patent application serial no. PCT/US00/18635, attorney docket no. 25791.25.02, filed on 7/9/2000, (11) U.S. provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (12) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (13) U.S. provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (14) U.S. provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (15) U.S. provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (16) U.S. provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (17) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (18) U.S. provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (19) U.S. provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (20) U.S. provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (21) U.S. provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (22) U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001, (23) U.S. provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (24) U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (25) U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (26) U.S. provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (27) U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, (28) U.S. provisional patent application serial no. 60/3318,386, attorney docket no.

25791.67.02, filed on 9/10/2001, (29) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (30) U.S. utility patent application serial no. 10/016,467, attorney docket no. 25791.70, filed on 12/10/2001; (31) U.S. provisional patent application serial no. 60/343,674, attorney docket no. 25791.68, filed on 12/27/2001; (32) U.S. provisional patent application serial no. 60/346,309, attorney docket no. 25791.92, filed on 1/7/2002; (33) U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/2002; (34) U.S. provisional patent application serial no. 60/372,632, attorney docket no. 25791.101, filed on 4/15/2002; and (35) U.S. provisional patent application serial no. 60/380,147, attorney docket no. 25791.104, filed on 5/6/2002, the disclosures of which are incorporated herein by reference.

Background of the Invention

[003] This invention relates generally to oil and gas exploration, and in particular to forming and repairing wellbore casings to facilitate oil and gas exploration and production.

[004] Conventionally, when a wellbore is created, a number of casings are installed in the borehole to prevent collapse of the borehole wall and to prevent undesired outflow of drilling fluid into the formation or inflow of fluid from the formation into the borehole. The borehole is drilled in intervals whereby a casing which is to be installed in a lower borehole interval is lowered through a previously installed casing of an upper borehole interval. As a consequence of this procedure the casing of the lower interval is of smaller diameter than the casing of the upper interval. Thus, the casings are in a nested arrangement with casing diameters decreasing in downward direction. Cement annuli are provided between the outer surfaces of the casings and the borehole wall to seal the casings from the borehole wall. As a consequence of this nested arrangement a relatively large borehole diameter is required at the upper part of the wellbore. Such a large borehole diameter involves increased costs due to heavy casing handling equipment, large drill bits and increased volumes of drilling fluid and drill cuttings. Moreover, increased drilling rig time is involved due to required cement pumping, cement hardening, required equipment changes due to large variations in hole diameters drilled in the course of the well, and the large volume of cuttings drilled and removed.

[005] The present invention is directed to overcoming one or more of the limitations of the existing processes for forming and repairing wellbore casings.

Summary of the Invention

[006] According to one aspect of the present invention, a method of radially expanding and plastically deforming at least a portion of an expandable tubular member is provided that includes positioning a resilient member within the interior of the expandable tubular member, and compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member.

[007] According to another aspect of the present invention, a system for radially expanding and plastically deforming at least a portion of an expandable tubular member is provided that includes means for positioning a resilient member within the interior of the expandable tubular member, and

means for compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member.

[008] According to another aspect of the present invention, an apparatus for radially expanding and plastically deforming an expandable tubular member is provided that includes a support member, a resilient member coupled to the support member, and an actuator operably coupled to the resilient member for controllably compressing the resilient member to thereby radially expand and plastically deform the expandable tubular member.

Brief Description of the Drawings

[009] Fig. 1a is a fragmentary cross-sectional illustration of an exemplary embodiment of an apparatus for radially expanding and plastically deforming a tubular member.

[0010] Fig. 1b is a fragmentary cross-sectional illustration of the apparatus of Fig. 1a after compressing the resilient expansion member to radially expand and plastically deform a portion of the expandable tubular member.

[0011] Fig. 1c is a fragmentary cross-sectional illustration of the apparatus of Fig. 1b after permitting the resilient expansion member to re-expand in the longitudinal direction.

[0012] Fig. 1d is a fragmentary cross-sectional illustration of the apparatus of Fig. 1c after removing the resilient expansion member from the expandable tubular member.

[0013] Fig. 1e is a fragmentary cross sectional illustration of the apparatus of Fig. 1d after positioning an adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member.

[0014] Fig. 1f is a fragmentary cross-sectional illustration of the apparatus of Fig. 1e after expanding the adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member.

[0015] Fig. 1g is a fragmentary cross sectional illustration of the apparatus of Fig. 1f after displacing the adjustable expansion cone relative to the expandable tubular member to radially expand and plastically deform at least a portion of the expandable tubular member.

[0016] Fig. 2a is a fragmentary cross-sectional illustration of the apparatus of Fig. 1a after being positioned within a preexisting structure.

[0017] Fig. 2b is a fragmentary cross sectional of the apparatus of Fig. 2a after compressing the resilient expansion member to radially expand and plastically deform a portion of the expandable tubular member into intimate contact with the interior surface of the preexisting structure.

[0018] Fig. 2c is a fragmentary cross-sectional illustration of the apparatus of Fig. 2b after permitting the resilient expansion member to re-expand in the longitudinal direction.

[0019] Fig. 2d is a fragmentary cross-sectional illustration of the apparatus of Fig. 2c after removing the resilient expansion member from the expandable tubular member.

[0020] Fig. 2e is a fragmentary cross sectional illustration of the apparatus of Fig. 2d after positioning an adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member.

[0021] Fig. 2f is a fragmentary cross-sectional illustration of the apparatus of Fig. 2e after expanding the adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member.

[0022] Fig. 2g is a fragmentary cross sectional illustration of the apparatus of Fig. 2f after displacing the adjustable expansion cone relative to the expandable tubular member to radially expand and plastically deform at least a portion of the expandable tubular member.

[0023] Fig. 3 is a fragmentary cross-sectional illustration of the radial expansion and plastic deformation of the expandable tubular member of Fig. 2a at a plurality of discrete locations by repeating the operational steps of Figs. 2a-2c a plurality of times within the preexisting structure.

[0024] Fig. 4 is a fragmentary cross sectional illustration of an alternative embodiment of the apparatus of Fig. 1a in which an adjustable expansion cone is provided below the resilient expansion member.

Detailed Description of the Illustrative Embodiments

[0025] Referring to Fig. 1a, a cylindrical member 10 that includes a flange 12 at one end is positioned within a first tubular member 14 that defines a passage 16 for receiving and mating with the flange of the cylindrical member. A second tubular member 18 that is received within and mates with the passage 16 of the first tubular member 14 defines a passage 20 that receives and mates with another end of the cylindrical member 10, and a third tubular member 22 that is also received within and mates with the passage of the first tubular member defines a passage 24 that receives and mates with an intermediate portion of the cylindrical member. In this manner, the third tubular member 22 is positioned between an end face of the second tubular member 18 and an end face of the flange 12 of the cylindrical member 10. An actuator 25 is operably coupled to the second tubular member 18 for controllably displacing the second tubular member relative to the cylindrical member 10 in the longitudinal direction. In an exemplary embodiment, the cylindrical member 10, the first tubular member 14, and the second tubular member 18 are fabricated from rigid materials such as, for example, aluminum or steel, and the third tubular member 22 is fabricated from resilient materials such as, for example, natural rubber, synthetic rubber, and/or an elastomeric material.

[0026] In an exemplary embodiment, as illustrated in Fig. 1b, the second tubular member 18 is then displaced downwardly in the longitudinal direction toward the flange 12 of the cylindrical member 10 by the actuator 25. As a result, the resilient third tubular member 22 is compressed in the longitudinal direction and expanded in the radial direction thereby radially expanding and plastically deforming the portion 26 of the first tubular member 14 proximate the radially expanded portion of the third tubular member 22. In an experimental implementation, the inside diameter of the portion

26 of the first tubular member 14 proximate the radially expanded portion of the third resilient tubular member 22 was unexpectedly increased by up to about 22 percent.

[0027] In an exemplary embodiment, as illustrated in Fig. 1c, the second tubular member 18 is then displaced upwardly in the longitudinal direction away from the flange 12 of the cylindrical member 10 by the actuator 25. As a result, the resilient third tubular member 22 is no longer compressed in the longitudinal direction or expanded in the radial direction. As a result, as illustrated in Fig. 1d, the cylindrical member 10, the second tubular member 18, and the third tubular member 22 may then be removed from the passage 16 of the first tubular member 14.

[0028] In an exemplary embodiment, as illustrated in Fig. 1e, an adjustable expansion cone 28 is then positioned within the radially expanded portion 26 of the first tubular member 14 using a support member 30.

[0029] In an exemplary embodiment, as illustrated in Fig. 1f, the outside diameter of the adjustable expansion cone 28 is then increased to mate with the inside surface of at least a portion of the radially expanded portion 26 of the first tubular member 14. The adjustable expansion cone 28 is then displaced upwardly relative to the first tubular member 14. In several alternative embodiments, the adjustable expansion cone 28 is displaced upwardly relative to the first tubular member 14 by pulling the adjustable expansion cone 28 upwardly and/or by pressurizing the region 32 of the first tubular member below the adjustable expansion cone. In an exemplary embodiment, as illustrated in Fig. 1g, as a result of the upward displacement of the adjustable expansion cone 28 relative to the first tubular member 14, an upper portion 34 of the first tubular member is radially expanded and plastically deformed.

[0030] In several exemplary embodiments, the upper portion 34 of the first tubular member 14 is radially expanded and plastically deformed using the adjustable expansion cone 28 in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) U.S. patent application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, (4) U.S. patent application serial no. 09/440,338, attorney docket no. 25791.9.02, filed on 11/15/1999, (5) U.S. patent application serial no. 09/523,460, attorney docket no. 25791.11.02, filed on 3/10/2000, (6) U.S. patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, (7) U.S. patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, (8) U.S. patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, (9) U.S. patent application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, (10) PCT patent application serial no. PCT/US00/18635, attorney docket no. 25791.25.02, filed on 7/9/2000, (11) U.S. provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (12) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (13) U.S. provisional patent application

serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (14) U.S. provisional-patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (15) U.S. provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (16) U.S. provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (17) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (18) U.S. provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (19) U.S. provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (20) U.S. provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (21) U.S. provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (22) U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001, (23) U.S. provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (24) U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (25) U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (26) U.S. provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (27) U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, (28) U.S. provisional patent application serial no. 60/3318,386, attorney docket no. 25791.67.02, filed on 9/10/2001, (29) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (30) U.S. utility patent application serial no. 10/016,467, attorney docket no. 25791.70, filed on 12/10/2001; (31) U.S. provisional patent application serial no. 60/343,674, attorney docket no. 25791.68, filed on 12/27/2001; (32) U.S. provisional patent application serial no. 60/346,309, attorney docket no. 25791.92, filed on 1/7/2002; (33) U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/2002; (34) U.S. provisional patent application serial no. 60/372,632, attorney docket no. 25791.101, filed on 4/15/2002; and (35) U.S. provisional patent application serial no. 60/380,147, attorney docket no. 25791.104, filed on 5/6/2002, the disclosures of which are incorporated herein by reference.

[0031] In several alternative embodiments, the upper portion 34 of the first tubular member 14 is radially expanded and plastically deformed using other conventional methods for radially expanding and plastically deforming tubular members such as, for example, internal pressurization and/or roller expansion devices such as, for example, that disclosed in U.S. patent application publication no. US 2001/0045284 A1, the disclosure of which is incorporated herein by reference.

[0032] In several alternative embodiments, the lower portion 36 of the first tubular member 14 is radially expanded and plastically deformed instead of, or in addition to, the upper portion 34.

[0033] Referring to Fig. 2a, in an alternative embodiment, the cylindrical member 10, the first tubular member 14, the second tubular member 18, and the third tubular member 22 are positioned

within the interior of a preexisting structure 38. In several exemplary embodiments, the preexisting structure 38 may be a wellbore, a wellbore casing, a pipeline, or a structural support.

[0034] In an exemplary embodiment, as illustrated in Fig. 2b, the second tubular member 18 is then displaced downwardly in the longitudinal direction toward the flange 12 of the cylindrical member 10 using the actuator 25. As a result, the resilient third tubular member 22 is compressed in the longitudinal direction and expanded in the radial direction thereby radially expanding and plastically deforming the portion 26 of the first tubular member 14 proximate the radially expanded portion of the third tubular member 22 into intimate contact with the interior surface of the preexisting structure 38. In an experimental implementation, the inside diameter of the portion 26 of the first tubular member 14 proximate the radially expanded portion of the third resilient tubular member 22 was unexpectedly increased by up to about 22 percent. In an experimental implementation, the contact pressure between the radially expanded and plastically deformed portion 26 of the first tubular member 14 and the interior surface of the preexisting structure 38 provided a fluid tight seal and supported the first tubular member.

[0035] In an exemplary embodiment, as illustrated in Fig. 2c, the second tubular member 18 is then displaced upwardly in the longitudinal direction away from the flange 12 of the cylindrical member 10 using the actuator 25. As a result, the resilient third tubular member 22 is no longer compressed in the longitudinal direction or expanded in the radial direction. As a result, as illustrated in Fig. 2d, the cylindrical member 10, the second tubular member 18, and the third tubular member 22 may then be removed from the passage 16 of the first tubular member 14.

[0036] In an exemplary embodiment, as illustrated in Fig. 2e, an adjustable expansion cone 28 is then positioned within the radially expanded portion 26 of the first tubular member 14 using a support member 30.

[0037] In an exemplary embodiment, as illustrated in Fig. 2f, the outside diameter of the adjustable expansion cone 28 is then increased to mate with the inside surface of at least a portion of the radially expanded portion 26 of the first tubular member 14. The adjustable expansion cone 28 is then displaced upwardly relative to the first tubular member 14. In several alternative embodiments, the adjustable expansion cone 28 is displaced upwardly relative to the first tubular member 14 by pulling the adjustable expansion cone 28 upwardly and/or by pressurizing the region 32 of the first tubular member below the adjustable expansion cone. In an exemplary embodiment, as illustrated in Fig. 2g, as a result of the upward displacement of the adjustable expansion cone 28 relative to the first tubular member 14, an upper portion 34 of the first tubular member is radially expanded and plastically deformed. In an exemplary experimental implementation, the upward displacement of the adjustable expansion cone 28 relative to the first tubular member 14, caused the upper portion 34 of the first tubular member to be radially expanded and plastically deformed into intimate contact with the interior surface of the preexisting structure.

[0038] In an alternative embodiment, as illustrated in Fig. 3, the first tubular member 14 is radially expanded and plastically deformed into intimate contact with the preexisting structure 38 at a plurality of spaced apart locations by operating the cylindrical member 10, the first tubular member 14, the second tubular member 18, and the third tubular member 22 a plurality of times as described above with reference to Figs. 2a-2c. As a result, radially expanded and plastically deformed portions, 26a and 26b, of the first tubular member 14 are thereby radially expanded and plastically deformed into intimate contact with interior surface of the preexisting structure 38. In an exemplary experimental implementation, the radially expanded and plastically deformed portions, 26a and 26b, of the first tubular member 14 provided a fluid tight seal between the radially expanded portions and the interior surface of the preexisting structure 38. In an exemplary embodiment, the intermediate portion 40 of the first tubular member 14, positioned between the radially expanded and plastically deformed portions, 26a and 26b, of the first tubular member, includes one or more openings, slots, and/or apertures for conveying fluidic materials into and/or out of the first tubular member. In this manner, fluidic materials within a subterranean formation 42 positioned proximate the intermediate portion may be extracted into the interior 16 of the first tubular member. Or, alternatively, fluidic materials may be injected into the subterranean formation. In several alternative embodiments, the subterranean formation 42 may include a source of hydrocarbons such as, for example, petroleum and/or natural gas, and/or a source of geothermal energy.

[0039] In an alternative embodiments, as illustrated in Fig. 4, an adjustable expansion cone 42 is coupled to the cylindrical member 10 below the resilient third tubular member 22. In this manner, during operation, after expanding the resilient tubular member 22 in the radial direction to thereby radially expand and plastically deform the first tubular member 14, the adjustable expansion cone 42 may then be positioned proximate the radially expanded portion of the first tubular member and radially expanded. The adjustable expansion cone 42 may then be displaced upwardly and/or downwardly relative to the first tubular member 14 in the longitudinal direction to thereby radially expand and plastically deform at least a portion of the first tubular member.

[0040] A method of radially expanding and plastically deforming at least a portion of an expandable tubular member has been described that includes positioning a resilient member within the interior of the expandable tubular member, and compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member. In an exemplary embodiment, the inside diameter of the radially expanded portion of the expandable tubular member is increased by up to about 22 percent during the radial expansion and plastic deformation. In an exemplary embodiment, the method further includes positioning an adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member, expanding the adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member, and displacing the adjustable expansion cone relative to the expandable tubular member in the longitudinal direction

to radially expand and plastically deform another portion of the expandable tubular member. In an exemplary embodiment, the method further includes decompressing the resilient member within the interior of the expandable tubular member, positioning the resilient member to another location within the interior of the expandable tubular member, and compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform another portion of the expandable tubular member. In an exemplary embodiment, the method further includes positioning the expandable tubular member within a preexisting structure. In an exemplary embodiment, the preexisting structure includes a wellbore. In an exemplary embodiment, the preexisting structure includes a wellbore casing. In an exemplary embodiment, the preexisting structure includes a pipeline. In an exemplary embodiment, the preexisting structure includes a structural support. In an exemplary embodiment, the method further includes compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member into contact with the interior surface of the preexisting structure. In an exemplary embodiment, the method further includes decompressing the resilient member within the interior of the expandable tubular member, positioning the resilient member to another location within the interior of the expandable tubular member, and compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform another portion of the expandable tubular member into contact with the interior surface of the preexisting structure. In an exemplary embodiment, the intermediate portion of the expandable tubular member positioned between the radially expanded and plastically deformed portions defines one or more radial openings for conveying fluidic materials between the interiors of the expandable tubular member and the preexisting structure. In an exemplary embodiment, the preexisting structure includes a wellbore that traverses a subterranean formation. In an exemplary embodiment, the subterranean formation includes a source of geothermal energy. In an exemplary embodiment, the subterranean formation includes a source of hydrocarbons. In an exemplary embodiment, the method further includes compressing the resilient member in the longitudinal direction within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member. In an exemplary embodiment, the resilient member is a resilient tubular member. In an exemplary embodiment, the expandable tubular member is a solid expandable tubular member. In an exemplary embodiment, the expandable tubular member defines one or more radial openings for conveying fluidic materials.

[0041] A system for radially expanding and plastically deforming at least a portion of an expandable tubular member has been described that includes means for positioning a resilient member within the interior of the expandable tubular member, and means for compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member. In an exemplary embodiment, the inside diameter of the radially expanded portion of the expandable tubular member is increased by up to

about 22 percent during the radial expansion and plastic deformation. In an exemplary embodiment, the system further includes means for positioning an adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member, means for expanding the adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member, and means for displacing the adjustable expansion cone relative to the expandable tubular member in the longitudinal direction to radially expand and plastically deform another portion of the expandable tubular member. In an exemplary embodiment, the system further includes means for decompressing the resilient member within the interior of the expandable tubular member, means for positioning the resilient member to another location within the interior of the expandable tubular member, and means for compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform another portion of the expandable tubular member. In an exemplary embodiment, the system further includes means for positioning the expandable tubular member within a preexisting structure. In an exemplary embodiment, the preexisting structure includes a wellbore. In an exemplary embodiment, the preexisting structure includes a wellbore casing. In an exemplary embodiment, the preexisting structure includes a pipeline. In an exemplary embodiment, the preexisting structure includes a structural support. In an exemplary embodiment, the system further includes means for compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member into contact with the interior surface of the preexisting structure. In an exemplary embodiment, the system further includes means for decompressing the resilient member within the interior of the expandable tubular member, means for positioning the resilient member to another location within the interior of the expandable tubular member, and means for compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform another portion of the expandable tubular member into contact with the interior surface of the preexisting structure. In an exemplary embodiment, an intermediate portion of the expandable tubular member positioned between the radially expanded and plastically deformed portions defines one or more radial openings for conveying fluidic materials between the interiors of the expandable tubular member and the preexisting structure. In an exemplary embodiment, the preexisting structure includes a wellbore that traverses a subterranean formation. In an exemplary embodiment, the subterranean formation includes a source of geothermal energy. In an exemplary embodiment, the subterranean formation includes a source of hydrocarbons. In an exemplary embodiment, the system further includes means for compressing the resilient member in the longitudinal direction within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member. In an exemplary embodiment, the resilient member includes a resilient tubular member. In an exemplary embodiment, the expandable tubular member is a solid expandable tubular

member. In an exemplary embodiment, the expandable tubular member defines one or more radial openings for conveying fluidic materials.

[0042] An apparatus for radially expanding and plastically deforming an expandable tubular member has been described that includes a support member, a resilient member coupled to the support member, and an actuator operably coupled to the resilient member for controllably compressing the resilient member to thereby radially expand and plastically deform the expandable tubular member. In an exemplary embodiment, the resilient member includes a tubular resilient member. In an exemplary embodiment, the apparatus further includes an adjustable expansion cone coupled to the support member. In an exemplary embodiment, the actuator is adapted to compress the resilient member in the longitudinal direction and thereby cause the resilient member to expand in the radial direction. In an exemplary embodiment, the support member is fabricated from a rigid material. In an exemplary embodiment, the rigid material is selected from the group consisting of steel and aluminum. In an exemplary embodiment, the resilient member is fabricated from materials selected from the group consisting of natural rubber, synthetic rubber, and elastomeric material.

[0043] It is understood that variations may be made in the foregoing without departing from the scope of the invention. For example, the teachings of the present illustrative embodiments may be used to provide a wellbore casing, a pipeline, or a structural support. Furthermore, the elements and teachings of the various illustrative embodiments may be combined in whole or in part in some or all of the illustrative embodiments.

[0044] Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

Claims

1. A method of radially expanding and plastically deforming at least a portion of an expandable tubular member, comprising:
positioning a resilient member within the interior of the expandable tubular member; and
compressing the resilient member within the interior of the expandable tubular member to
radially expand and plastically deform a portion of the expandable tubular member.
2. The method of claim 1, wherein the inside diameter of the radially expanded portion of the expandable tubular member is increased by up to about 22 percent during the radial expansion and plastic deformation.
3. The method of claim 1, further comprising:
positioning an adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member;
expanding the adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member; and
displacing the adjustable expansion cone relative to the expandable tubular member in the longitudinal direction to radially expand and plastically deform another portion of the expandable tubular member.
4. The method of claim 1, further comprising:
decompressing the resilient member within the interior of the expandable tubular member;
positioning the resilient member to another location within the interior of the expandable tubular member; and
compressing the resilient member within the interior of the expandable tubular member to
radially expand and plastically deform another portion of the expandable tubular member.
5. The method of claim 1, further comprising:
positioning the expandable tubular member within a preexisting structure.
6. The method of claim 5, wherein the preexisting structure comprises a wellbore.
7. The method of claim 5, wherein the preexisting structure comprises a wellbore casing.
8. The method of claim 5, wherein the preexisting structure comprises a pipeline.

9. The method of claim 5, wherein the preexisting structure comprises a structural support.
10. The method of claim 5, further comprising:
compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member into contact with the interior surface of the preexisting structure.
11. The method of claim 10, further comprising:
decompressing the resilient member within the interior of the expandable tubular member;
positioning the resilient member to another location within the interior of the expandable tubular member; and
compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform another portion of the expandable tubular member into contact with the interior surface of the preexisting structure.
12. The method of claim 11, wherein an intermediate portion of the expandable tubular member positioned between the radially expanded and plastically deformed portions defines one or more radial openings for conveying fluidic materials between the interiors of the expandable tubular member and the preexisting structure.
13. The method of claim 12, wherein the preexisting structure comprises a wellbore that traverses a subterranean formation.
14. The method of claim 13, wherein the subterranean formation comprises a source of geothermal energy.
15. The method of claim 13, wherein the subterranean formation comprises a source of hydrocarbons.
16. The method of claim 1, further comprising:
compressing the resilient member in the longitudinal direction within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member.
17. The method of claim 1, wherein the resilient member comprises a resilient tubular member.

18. The method of claim 1, wherein the expandable tubular member comprises a solid expandable tubular member.

19. The method of claim 1, wherein the expandable tubular member defines one or more radial openings for conveying fluidic materials.

20. A system for radially expanding and plastically deforming at least a portion of an expandable tubular member, comprising:

means for positioning a resilient member within the interior of the expandable tubular member; and

means for compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member.

21. The system of claim 20, wherein the inside diameter of the radially expanded portion of the expandable tubular member is increased by up to about 22 percent during the radial expansion and plastic deformation.

22. The system of claim 20, further comprising:

means for positioning an adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member;

means for expanding the adjustable expansion cone within the radially expanded and plastically deformed portion of the expandable tubular member; and

means for displacing the adjustable expansion cone relative to the expandable tubular member in the longitudinal direction to radially expand and plastically deform another portion of the expandable tubular member.

23. The system of claim 20, further comprising:

means for decompressing the resilient member within the interior of the expandable tubular member;

means for positioning the resilient member to another location within the interior of the expandable tubular member; and

means for compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform another portion of the expandable tubular member.

24. The system of claim 20, further comprising:

means for positioning the expandable tubular member within a preexisting structure.

25. The system of claim 24, wherein the preexisting structure comprises a wellbore.
26. The system of claim 24, wherein the preexisting structure comprises a wellbore casing.
27. The system of claim 24, wherein the preexisting structure comprises a pipeline.
28. The system of claim 24, wherein the preexisting structure comprises a structural support.
29. The system of claim 24, further comprising:
means for compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member into contact with the interior surface of the preexisting structure.
30. The system of claim 29, further comprising:
means for decompressing the resilient member within the interior of the expandable tubular member;
means for positioning the resilient member to another location within the interior of the expandable tubular member; and
means for compressing the resilient member within the interior of the expandable tubular member to radially expand and plastically deform another portion of the expandable tubular member into contact with the interior surface of the preexisting structure.
31. The system of claim 30, wherein an intermediate portion of the expandable tubular member positioned between the radially expanded and plastically deformed portions defines one or more radial openings for conveying fluidic materials between the interiors of the expandable tubular member and the preexisting structure.
32. The system of claim 31, wherein the preexisting structure comprises a wellbore that traverses a subterranean formation.
33. The system of claim 32, wherein the subterranean formation comprises a source of geothermal energy.
34. The system of claim 32, wherein the subterranean formation comprises a source of hydrocarbons.

35. The system of claim 20, further comprising:
means for compressing the resilient member in the longitudinal direction within the interior of the expandable tubular member to radially expand and plastically deform a portion of the expandable tubular member.
36. The system of claim 20, wherein the resilient member comprises a resilient tubular member.
37. The system of claim 20, wherein the expandable tubular member comprises a solid expandable tubular member.
38. The system of claim 20, wherein the expandable tubular member defines one or more radial openings for conveying fluidic materials.
39. An apparatus for radially expanding and plastically deforming an expandable tubular member, comprising:
a support member;
a resilient member coupled to the support member; and
an actuator operably coupled to the resilient member for controllably compressing the resilient member to thereby radially expand and plastically deform the expandable tubular member.
40. The apparatus of claim 39, wherein the resilient member comprises a tubular resilient member.
41. The apparatus of claim 39, further comprising an adjustable expansion cone coupled to the support member.
42. The apparatus of claim 39, wherein the actuator is adapted to compress the resilient member in the longitudinal direction and thereby cause the resilient member to expand in the radial direction.
43. The apparatus of claim 39, wherein the support member is fabricated from a rigid material.
44. The apparatus of claim 43, wherein the rigid material is selected from the group consisting of steel and aluminum.
45. The apparatus of claim 39, wherein the resilient member is fabricated from materials selected from the group consisting of natural rubber, synthetic rubber, and elastomeric material.

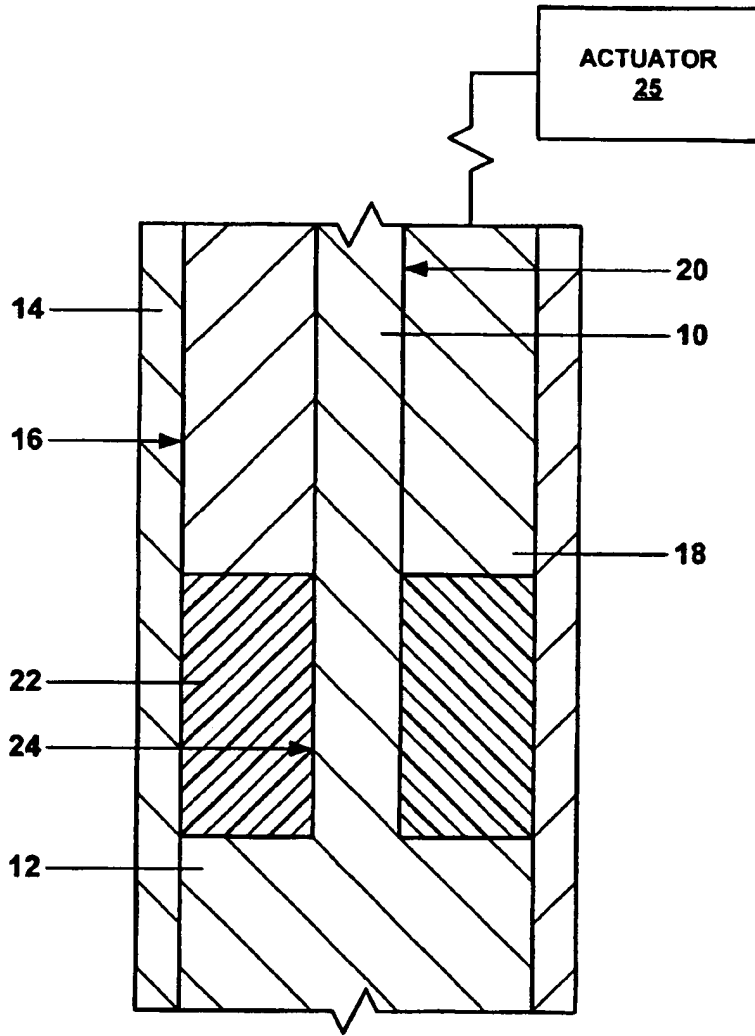


Fig. 1a

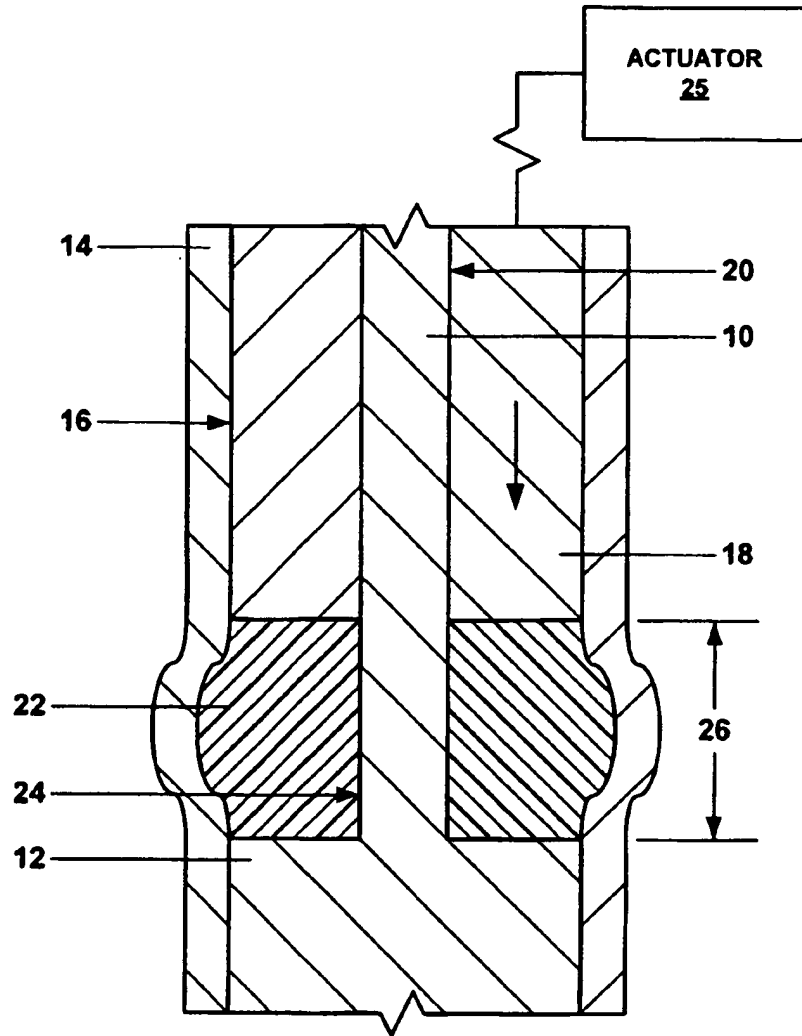


Fig. 1b

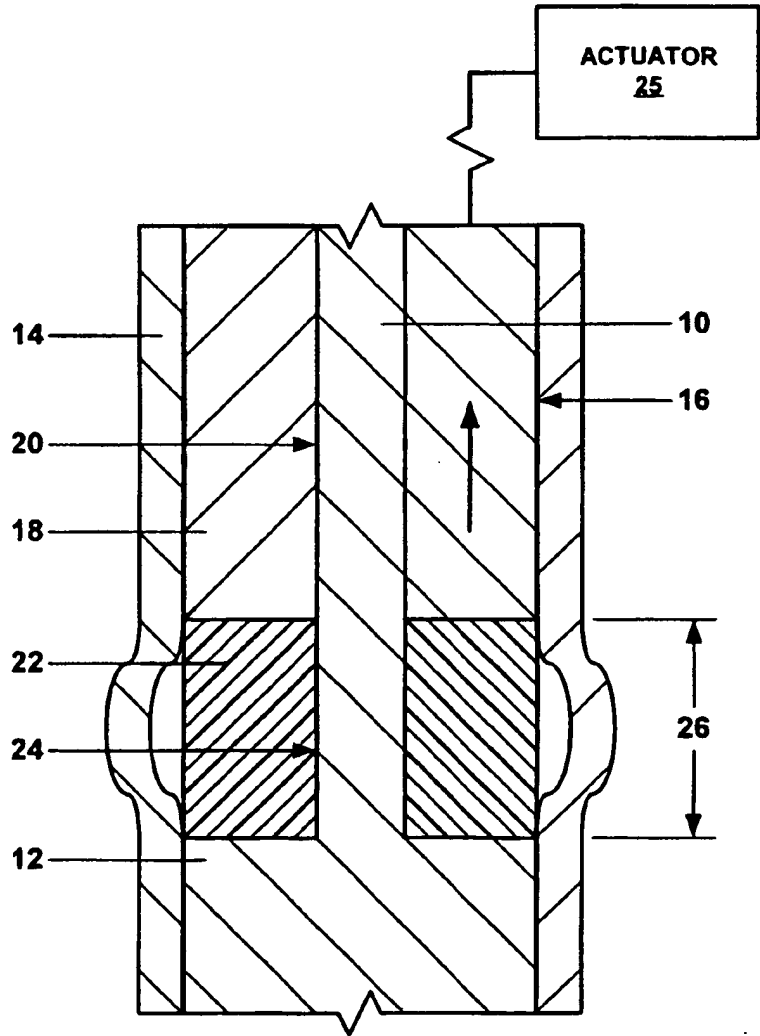


Fig. 1c

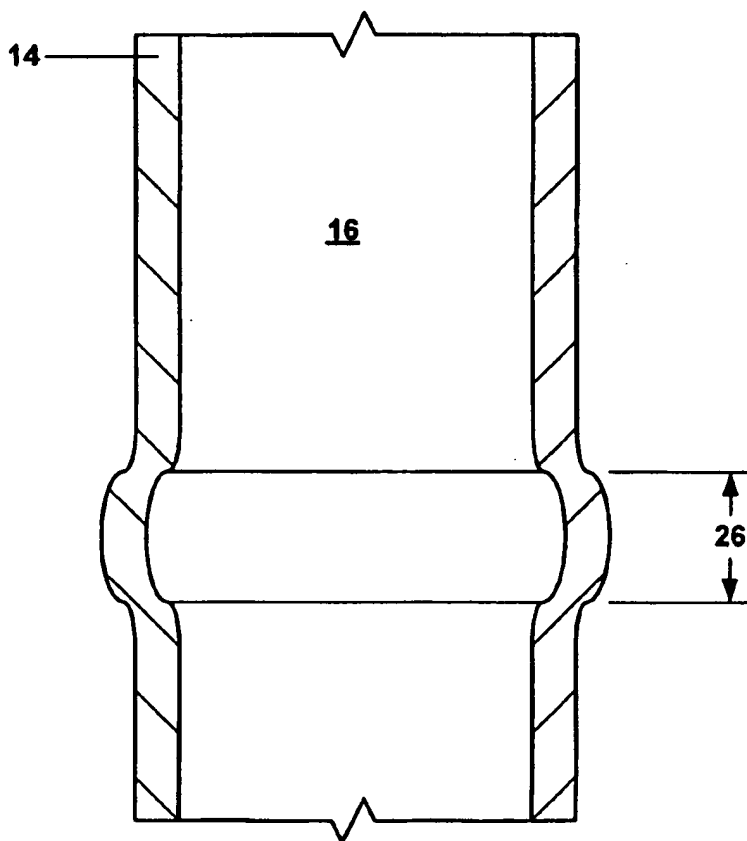


Fig. 1d

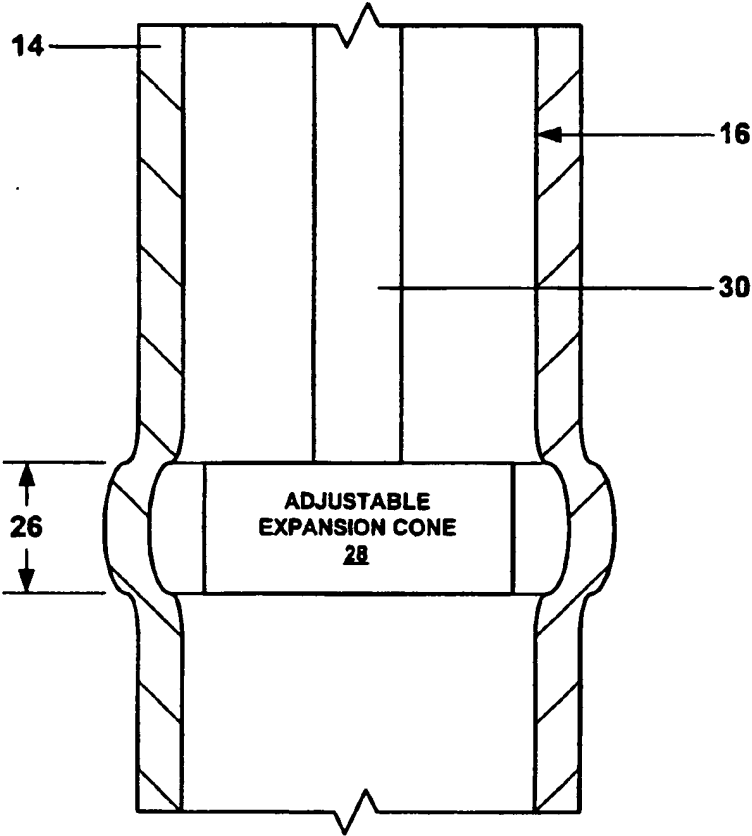


Fig. 1

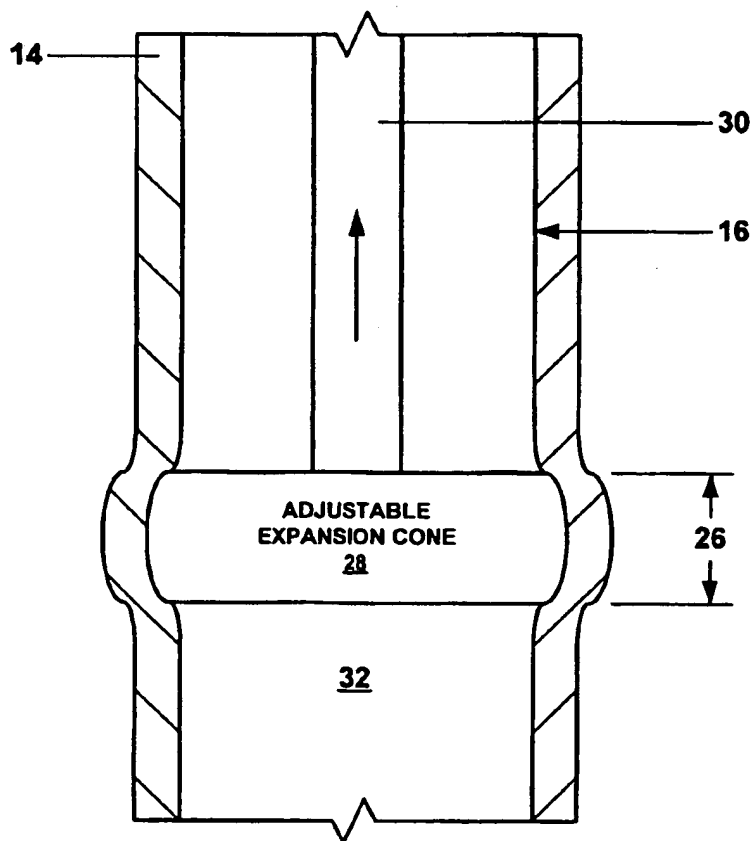


Fig. 1f

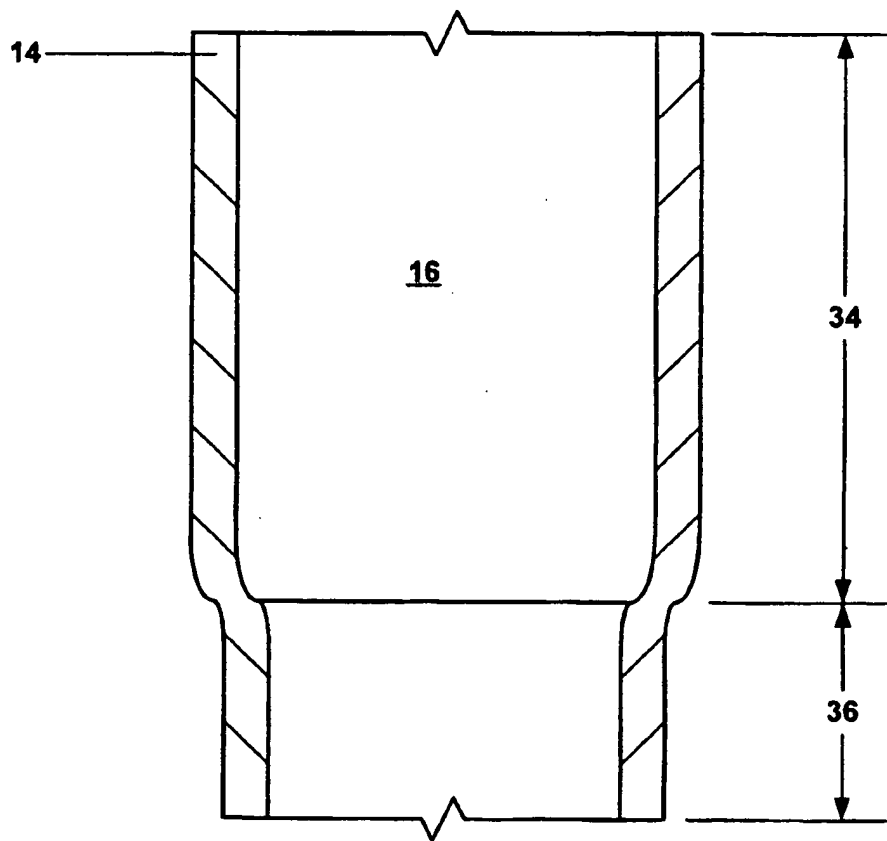


Fig. 1g

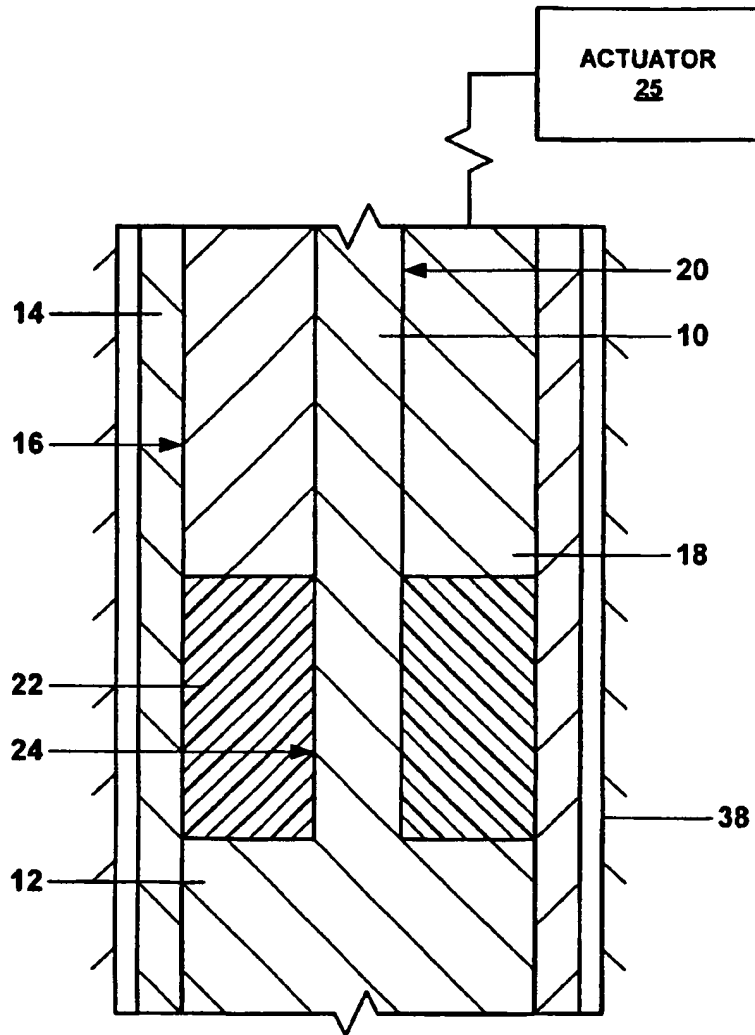


Fig. 2a

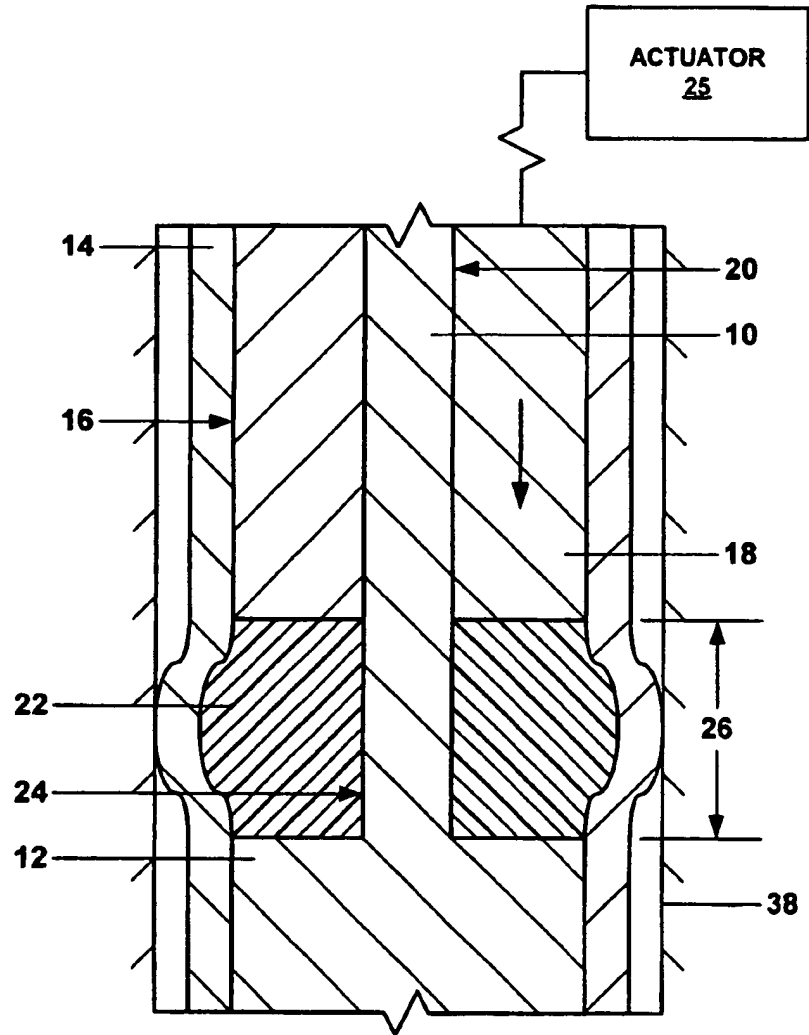


Fig. 2b

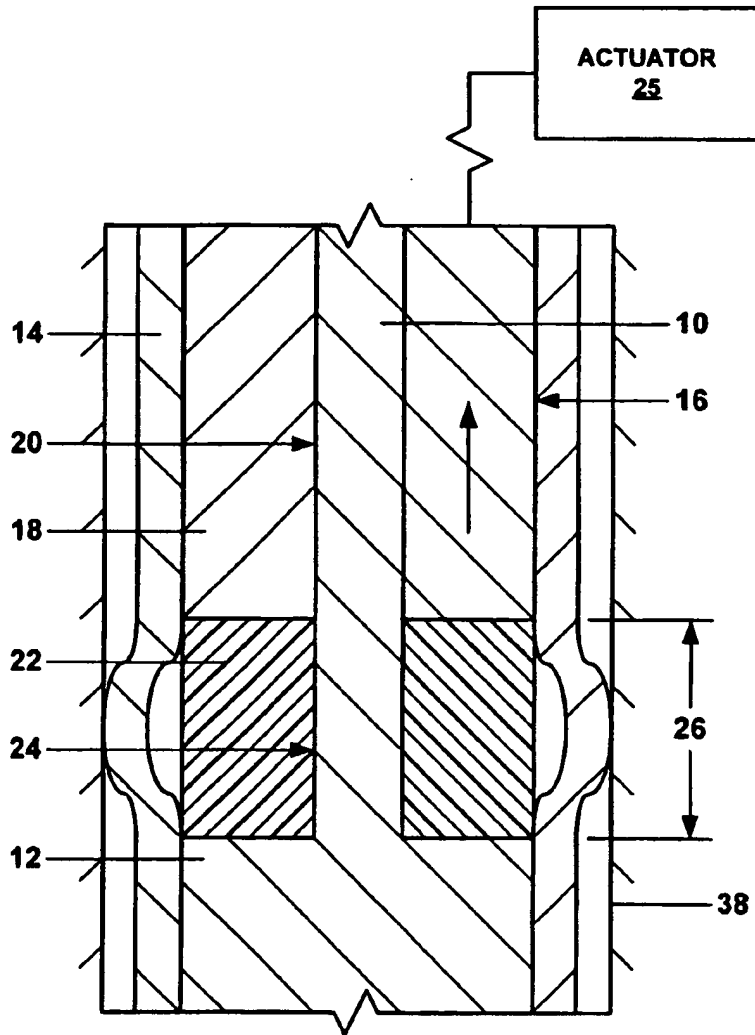


Fig. 2c

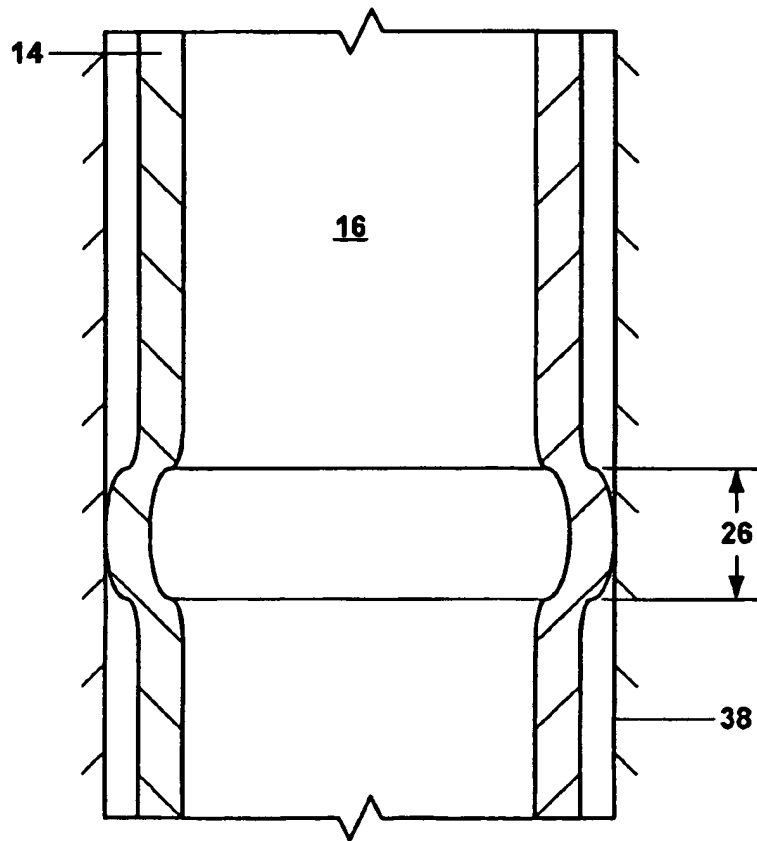


Fig. 2d

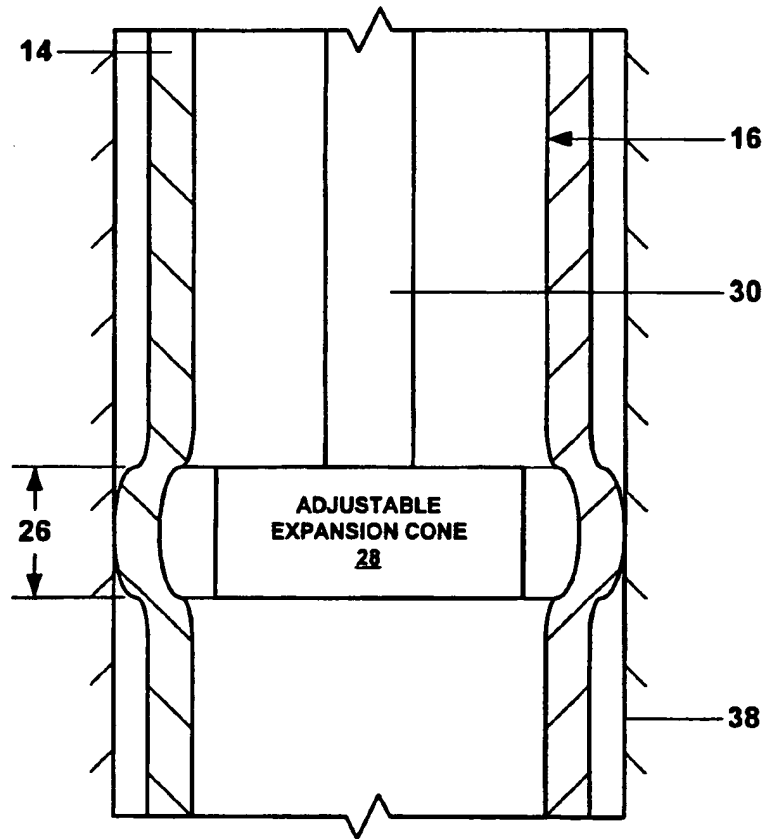


Fig. 2

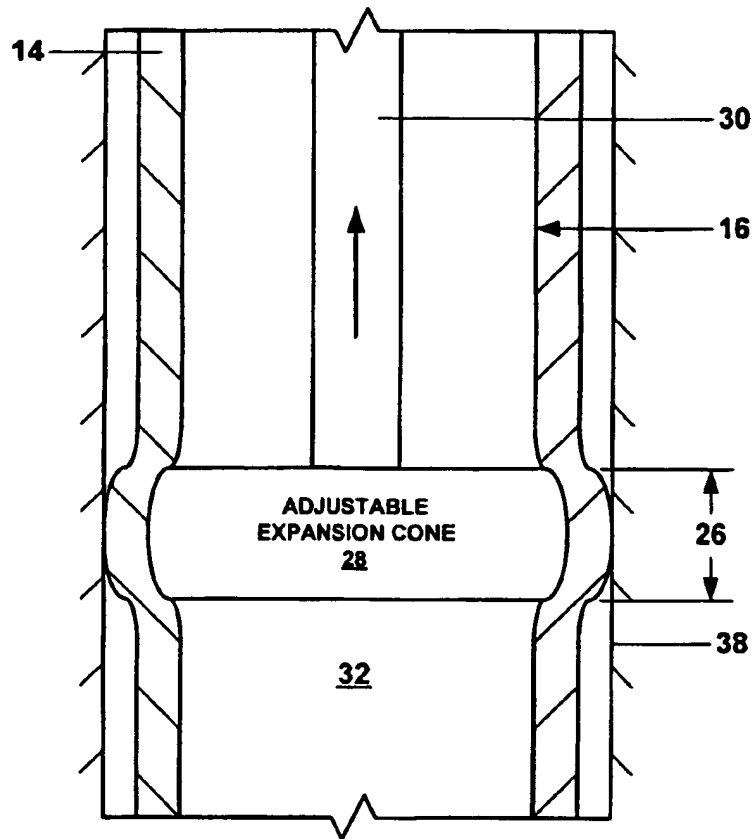


Fig. 2f

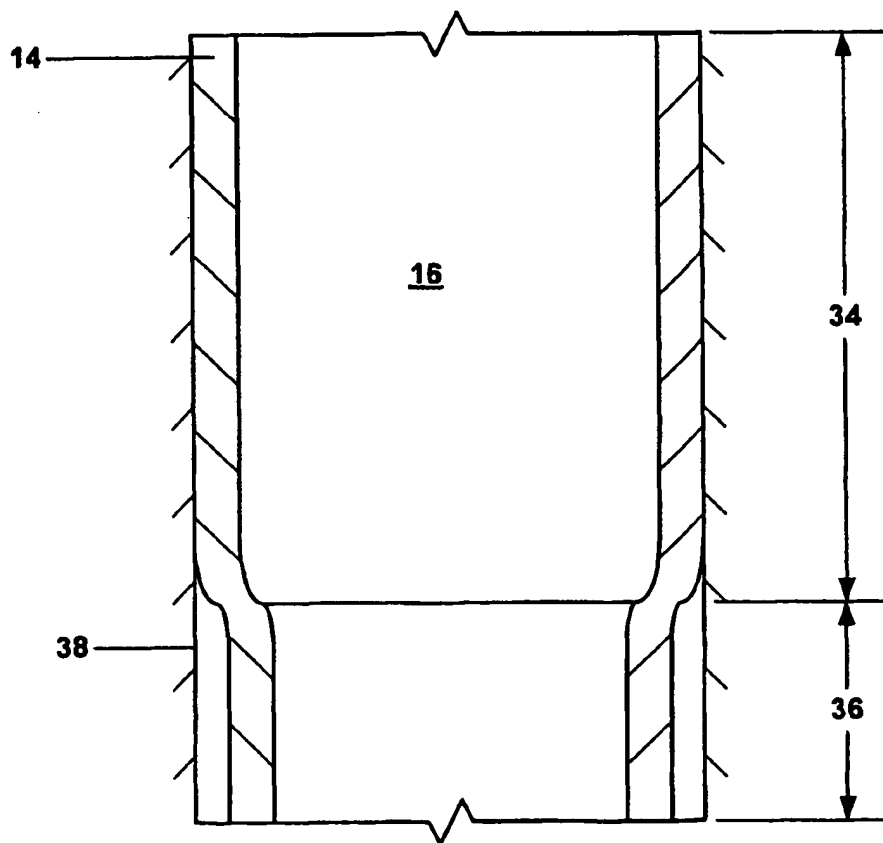


Fig. 2g

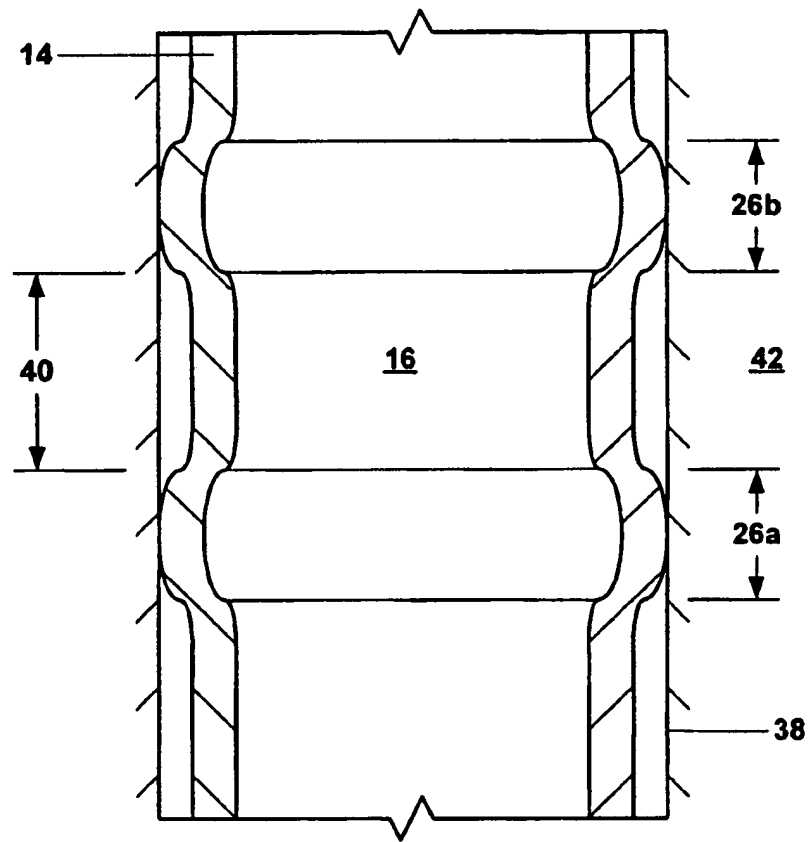


Fig. 3

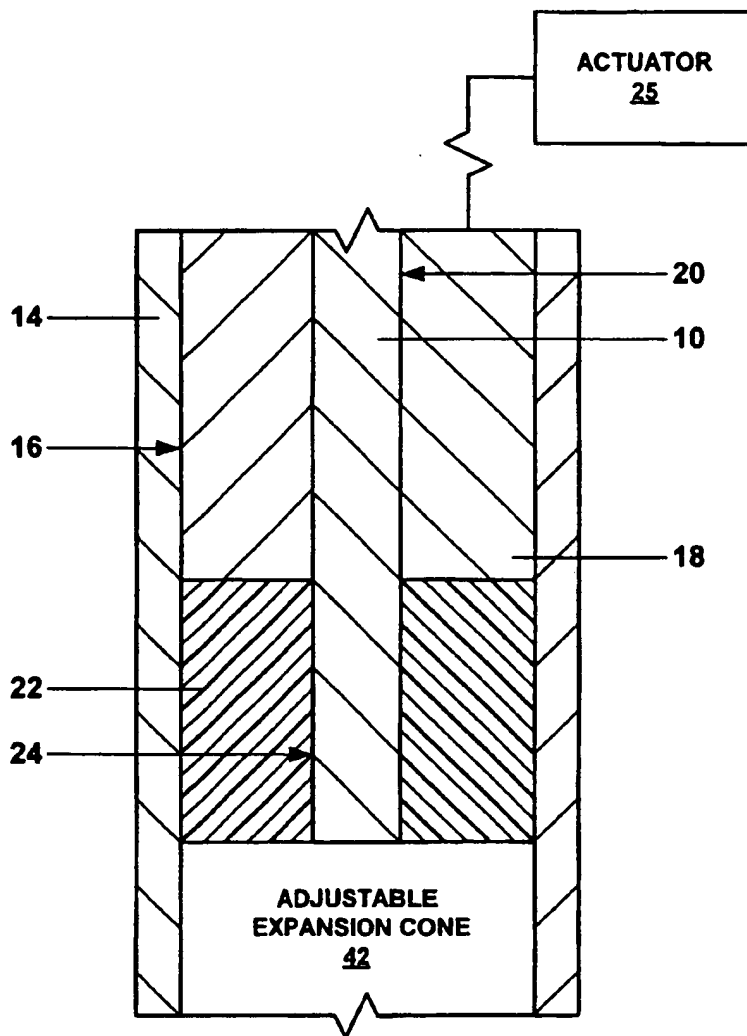


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US03/11765

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : E21B 43/10
 US CL : 166/207,206

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 U.S. : 166/207,206,217,382; 285/382.4,382.5

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,871,199 A (Ridenour et al.) 3 October 1989 (03.12.1989), Figure 5, col. 5, lines 46-65.	1-2, 16-18, 20-21, 35-37, 39-40, 42-45
X	US 4,581,817 A (Kelly) 15 April 1986 (15.04.1986), Entire document, Figures 2-3.	1-2, 5, 9-10, 16-18, 20-21, 24, 28-29, 35-37, 39-40, 42-45
X --- Y	US 4,422,317 A (Mueller) 27 December 1983 (27.12.1983), Figures 1-2, col. 1, lines 39-54)	1-2, 4, 16-18, 20-21, 23, 35-37, 39-40, 42-45 ----- 5, 10-15, 19, 24, 28-34, 38

Further documents are listed in the continuation of Box C. See patent family annex.

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"E" earlier application or patent published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

Date of the actual completion of the international search: 26 September 2003 (26.09.2003)
 Date of mailing of the international search report: 13 NOV 2003

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (703)305-3230	Authorized officer Lynne H. Browne Telephone No. 703-308-1113
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INTERNATIONAL SEARCH REPORT

PCT/US03/11765

C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,388,752 A (Vinciguerra et al.) 21 June 1983 (21.06.1983) Entire Document, Figures 1-2.	1-2, 5, 8-10, 16-18, 20-21, 24, 27-29, 35-37, 39-40, 42-45 ----- 6-7, 19, 25-26, 38
Y	US 6,6070,671 A (Cumming et al.) 6 June 2000 (06.06.2000), Figures 1 and 4.	5-7, and 24-26
Y	US 3,353,599 A (Swift) 21 November 1967 (21.11.1967) Figures 3-4	12-15, 19, 31-34, 38